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AUTO-ID CENTRE

WHITE PAPER

Auto-ID Use Case: Improving Usage and Tracing of Rework Pieces in a Global Food Manufacturer – Impact on Existing Procedures and Information Systems

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ABSTRACT

Determining the impact of Auto-ID implementations on existing procedures and related information systems is a difficult task, and requires deep analysis of both the current and Auto-ID-enhanced situation. Auto-ID offers many different implementation possibilities with various requirements, advantages and disadvantages, further complicating the impact analysis. This paper is an industrial application of the "Use Case Approach" (Morán et al, 2003) that determine the impact of using Auto-ID to improve the usage and tracing of rework pieces in one of several UK manufacturing plants of a Global Food Manufacturer. Speficically,rework management for a chocolate covered confectionery product. This industrial study is the second of four of this type developed in the UK and involved numerous interviews with knowledgeable people in this company, visitation of manufacturing facilities, and the thorough application of the aforementioned approach, which consisted of:

1. finding representative process improvement use cases – in terms of current operational procedures, issues, and implementation possibilities;
2. contrasting their associated operational procedures with the proposed ones; and
3. identifying the additional data and transactions required by their related information systems.

This paper concludes that changes in procedures are trivial, whereas most of the changes in information systems are required at the highest level: enterprise strategic planning and inventory management. Intermediate systems require only a few new transactions and data. The following points summarise the impact identified by this study:

1. Addition of rework entities, relationships and functionality in the highest software layer – ERP planning system and warehouse/stock management system.
2. Enhancement of the middleware system (Integration framework) to make it fully online, bidirectional and combine information from different sources such as Auto-ID, ERP, Tracking software, etc.
3. The location information should be extended to the shop floor – not only the warehouse.
4. Reingeenering of procedures and transactions to switch from a tracing-oriented to a supporting-oriented rework system.

This study did not find major implications related to entity or transaction granularity nor significant required changes in the current operational procedures.

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1. INTRODUCTION

This document covers the development and findings of an industrial application of the "Use Case Approach" proposed in a previous Auto-ID Centre publication (Morán et al, June 2003). It determines the impact of Auto-ID implementations on existing procedures and information systems, and shows the most evident and relevant implementation possibilities.

This white paper presents the tracking and tracing of rework pieces (surplus work in progress – WIP) as a case of use for Auto-ID technology, showing the impressive versatility of this promising technology. This specific use case leverages the Auto-ID tracking and tracing capabilities (its RFID capabilities), for all the information and product flows occur within the same company – there is no inter-organisational exchange of either goods or information.

This industrial study was made with the cooperation of the UK manufacturing systems team of a leading global food manufacturer. The analysis included a detailed review of the current rework system for a chocolate covered confectionery product within one of their UK plants. The current system is mainly supported by barcode tagging and manual scanning of pieces. As specified by the "Use Case Approach" paper, the research activity focused on its operational activities and related information systems. The main function of the rework system is to track rework pieces so that full traceability and accountability is given to any process order that subsequently use them. Additional functions include rework status measurement – using the system as a metric for factory performance and improvement.

The rework is currently managed using a barcode scanning process, in which cages of rework are barcoded. Operators scan these codes to identify the objects. The process then uses a scanning application in conjunction with a integration framework to manage the rework and create records of the rework in the Inventory Management module of the ERP system for traceability. This process has only recently been implemented in the plant and is a pilot program testing the use of barcodes for such applications.

The proposed Auto-ID enhanced process removes the need for barcodes and the labour intensive process of barcode scanning and tub counting that takes place nowdays. The Auto-ID-enhanced process allows a greater degree of confidence in tracking and tracing data that is communicated to both the Integration Framework and the ERP System. As a result manufacturing performance can be improved whilst reducing the recall size of embargoes.

This project had then four key aims:

1. Using Auto-ID technology to improve a real life process in the manufacturing sector.
2. Investigating the difficulties faced in integrating Auto-ID data into current business information systems.
3. Testing the methodology for designing Auto-ID enhanced processes in the manufacturing environment.
4. Learning from the experience.

The study involved interviews with knowledgeable people in the company, the visitation of various manufacturing facilities, and the analysis of the findings using the aforementioned approach. The following basic steps were followed:

1. Find representative use cases for process improvement, in terms of current operational procedures, issues, and implementation possibilities. This first step involved interviewing employees responsible for Auto-ID adoptions and IT innovation in general, and IT personnel in charge of manufacturing and inventory systems. It also involved visiting the manufacturing facilities and the detailed observation of manufacturing processes generating or consuming rework pieces. Some Auto-ID implementation possibilities were also identified by considering different technologies and configurations, and new complementary procedures were designed and proposed.

2. Contrast their associated operational procedures with the proposed ones. This step required the offline analysis of the information found in the previous one in the light of each implementation possibility.
3. Identify the additional data and transactions required in their related information systems. The supporting transactions and data currently performed or stored by the current information systems were identifying by interviewing knowledgeable people in the IT department.

The study also involved an extensive use of company documents referring to the rework process and to the global vision for rework processes.

1.1. Acknowledgements

We would like to express our deepest gratitude to the employees of the company who kindly and patiently cooperated in the multiple interviews and provided valuable support.

We would specially thank the manufacturing system's staff, who were responsible of the design and implementation of the current rework system and value and are keen to explore Auto-ID's possibilities.

1.2. Background

1.2.1. Business Information and Industrial Control Action Group, and Software Action Group
This research is part of the Auto-ID Centre's Business Information and Industrial Control Action Group activities. Combining both theoretical research and industrial studies, this group aims at identifying the impact of Auto-ID on business information and industrial control systems and developing frameworks, models and methodologies to deal with this impact and provide sound integration alternatives. The Business Information and Industrial Control Action Group also deals with business activities supported by commercial and bespoke information systems potentially suitable of improvement with Auto-ID, covering a broad area ranging from Auto-ID business strategy to Auto-ID use cases development and analysis of their impact on existing technology for business automation.

This research is also part of the Auto-ID Software Action Group, which aims at setting standards and legal frameworks for Auto-ID software developments. The Software Action Group recognises and proposes the development of specific use cases as a way of identifying technical requirements for the Savant™ and Auto-ID interfaces with business information systems.

1.2.2. Previous Works
This paper includes ideas from other previous papers: Timothy Milne and Amit Goyal's "Track and Trace Shipping and Verify Receiving Use Case" (April 2003), Timothy Milne's "Sub Group and Use Case Focus Group Methodology" (November 2002), Duncan McFarlane's "Auto-ID Based Control – An Overview" (January 2002), and "The Intelligent Product Driven Supply Chain" (Brock, David et al, January 2002). Yoon Chang and Duncan McFarlane have also proposed specific methodologies to support the integration of Auto-ID and business information systems, and have provided a thorough classification for the latter and an example use case – "Methodologies for integrating Auto-ID Data with existing Business Information Systems" (Chang et al, November 2002).

The research documented in this paper followed the steps and methodology suggested by the "Use Case Approach for Determining the Impact of Auto-ID Implementations on Business Information Systems" (Morán et al, June 2003). We will refer to this document as the "Use Case Approach". This approach also served to support other similar studies, such as the one documented in "Auto-ID Use Case: improving inventory visibility in a leading retail company – impact on existing procedures and information systems" (Morán et al, August 2003), which will be published by September 2003.

1.3. Industry and Use Case Characteristics

Nothing better describes the situation of the manufacturing industry in the UK than the following paragraph by the British Department of Trade and Industry:

> Manufacturing in the UK comprises a fifth of the economy and employs around 4 million people and many more in associated industries and services. Manufacturing accounts for 60% of British exports and 80% of research and development, so is a key driver of innovation and technology uptake. But manufacturing productivity in many other industrialised countries is higher than it is in the UK: around 30% more in France and Germany, and 55% more in the US. If UK manufacturers could match performance in these countries, the economy would be £70bn better off. Returns on investments would be higher, jobs better paid and companies more competitive. The UK has many world-class companies and real strengths to build on, including a stable macro-economic environment, a first class science base and membership of the EU giving access to the world's largest single market. But we also have significant weaknesses. UK manufacturers invest less in capital equipment on average than competitors. With a few exceptions we spend less on R&D and average skills levels are lower. The National Institute of Economic and Social Research has quantified the impact of this and other factors contributing to the productivity gap including business effectiveness at utilising capital, skills and innovation. We recognise the short-term challenges UK manufacturers have faced: falling manufacturing output across the G7, low global demand for products and the relative weakness of the euro have resulted in job losses and profits have fallen to significant lows. The increasing pace of globalisation presents many opportunities for increasing trade as barriers come down and capital becomes more mobile. But it also means that companies face increasing competition from goods and services produced in lower-waged economies. Companies that rely on labour-intensive products and processes will find it ever more difficult to compete unless they evolve to meet the challenges. **The evidence is clear that more innovative and knowledge-intensive products, processes and management are vital.** [1]

[1] British Department of Trade and Industry. www.dti.gov.uk

In a nutshell, fostering innovation and increasing investment in R&D are recognised as crucial factors to improve productivity in the manufacturing industry. Using Auto-ID to improve product quality and manufacturing competitiveness is an unambiguous answer to these requirements, and clearly justifies studies like the present one.

Following the classification proposed in the "Use Case Approach" white paper, the Rework Use Case is classified as a **Process Improvement Use Case**, for it focuses on specific operational areas of the organisation and involves no significant changes in the current business model.

1.4. Document Structure

The Manufacturing Rework Use Case is defined by the current situation; elements it touches; and the proposed changes. Described in section 2 of this paper, the former is specified in terms of:

1. Processes to improve: actors, procedure steps, product and information flows, activities, level of automation, decision points, contingency plans and supporting assets.
2. IT infrastructure supporting the rework system: systems and their main entities, transactions and interfaces.

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3. Limitations of the current technology; requirements, complementary technologies, undesired externalities etc.
4. Opportunities and issues to solve or improve: what would be "nice to have", although is impossible or prohibitive nowadays.
5. Auto-ID capabilities allowing the improvements: tracking, tracing or inter-organisational.
6. Implementation decisions: how to use Auto-ID to improve the rework system.
7. Potential benefits: qualitative benefits and valuation suggestions.

Described in section 3 of this paper, the latter – proposed changes – can be specified in terms of:

1. Affected systems and their characteristics.
2. Auto-ID-enhanced operational procedures.
3. Impact of new procedures on existing information systems.

In this paper, the affected systems and some of their characteristics were put in the Use Case definition section because it helps in identifying their relationship and eases the reading. The "proposed changes" section continues further into detail by specifying transactions and information flows.

2. USE CASE COMPONENTS

As explained in the "Use Case Approach" document, a Use Case is more than a simple description of the Auto-ID-enhanced procedures and advantages. It requires a thorough analysis and description of the current situation and a clear justification in terms of business benefits. That is, the Use Case must be framed within the business requirements themselves and under no circumstances should be justified for the sake of technology. In this section we list all the use case components in order to give a clear picture of the current situation and show why and where it offers improvement opportunities by means of Auto-ID.

2.1. Processes to Improve

Consequence of its imperfect nature, the manufacturing activity generates pieces of work in process that cannot make their way further in the production process because they do not comply with certain requirements – they are "out of spec". These pieces are drained out of the production line asking for alternative dealing out. They are generated by failing machines, human errors or waste in the starting and ending points of production. They may also result from normal operation as some machines are unable to use all materials in an optimum way and hence generate "clean waste" in the process.
An example of this is the generation of uneven edges when chopping chocolate pieces. Furthermore, surplus WIP pieces can result from products exceeding consumer demand or from manufacturing R&D experiments. Some of them are created during start-up and shutdown or changeover of the system, and some are also created by process fluctuations that result in a dimensionally inaccurate products or products of the wrong composition or weight during normal operation. Most surplus WIP detection is automated using standard sensors although some intervention by operators frequently takes place.

Surplus WIP can be classified as:

Recycled product – "clean waste" created and consumed within the same process order. This will be a throughput loss, but has no effect on traceability.

Rework– “clean waste” created on one process order and consumed on a subsequent process order. This will be a throughput loss, and has an effect on traceability.

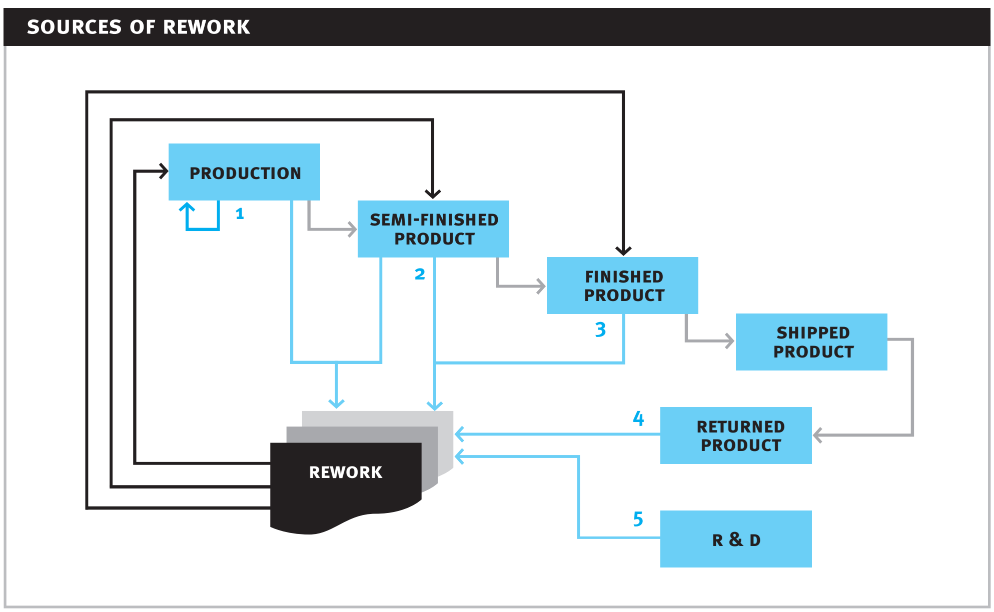
Employees Sales, and Animal food – “clean waste” created but unable to be re-used in production – for whatever reason – scuffing, too much rework available, etc.

Floor waste – Unfit for human consumption. Can be product spilled from the plant, or rework downgraded due to age, etc.

The second type of surplus WIP is called rework because most of these pieces are fed back upstream into the manufacturing process for production economics: raw material such as chocolate can be expensive but easy and safe to reuse, making its recycling a sensible option. Moreover, productions recipes often specify a percentage of rework to homogenise quality, so these rework pieces may be a fundamental part of the manufacturing process as well. The others “out of spec” pieces may involve disposing or selling them for purposes other than human consumption. Getting rid of these materials may in turn involve either to convert them to animal food or simply throw them away. What is done with them depends on their quality, age, and nature – e.g. expensive chocolate pieces are more likely to be reused.

This study focuses on the rework produced in the manufacturing of small chocolate covered confectionery items. Rework pieces can be either coated or uncoated confectionery. Both coated and uncoated rework can be reused in small quantities at the start of the process to make up one of the constituent parts (the filling).

Figure 1: Shows the sources of rework in this process.



In a nutshell, rework pieces are generated along the production process and even at its very end. For example, when the final product does not meet the minimum quality standards or is returned. This process is known as product downgrading.

Controlling rework pieces is important for they have a direct impact on product quality. Moreover, as rework may produce raw material cross-feeding, tracing rework pieces is crucial to comply with regulations and allow for selective product recalls when needed. Although economically advantageous, the rework process complicates the manufacturing activity as different materials are mixed up during the rework reuse, affecting product quality and posing tremendous challenges to raw-material tracing in final products.

The current system used to support creating, moving, storing and reusing rework pieces involves their identification and tracking by means of barcodes. All rework pieces are clearly identified and their information stored in specialised information systems that support the tracking. Nevertheless, and as explained in the "limitations of the current technology" section, the current system is suitable of improvement.

To break down the process further we consider the operation in three parts:

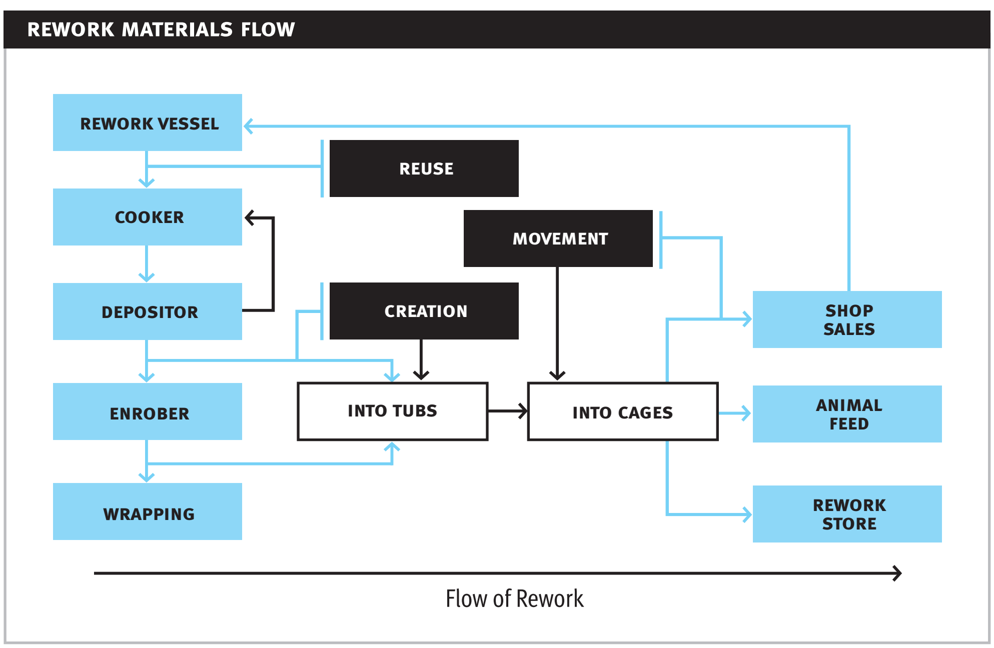
Rework creating: how rework pieces are created and labelled during the manufacturing process. This process involves the collecting, aggregating, verifying, classifying and labelling of rework units.

Rework movement: what to do with the rework pieces, how are they transported and stored, and which events trigger these actions. This process involves scanning the pieces; deciding what to do with them – reuse, send to animal food manufacturing, dispose or sale them; moving them; and selecting a place to store them.

Reuse of Rework: when to use rework pieces, which ones to pick from the warehouse, and where to find them. This process involves deciding which pieces to use, scanning them so the system associates them with the current manufacturing run and resulting products, transporting them to the reusing vessel.

The following drawing helps understanding the rework material flows and related procedures:

Figure 2: Rework Materials Flow and associated procedures

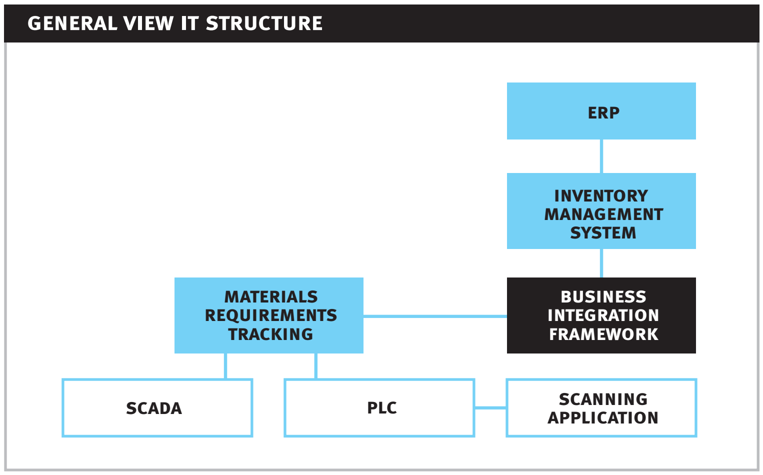


2.2. IT Infrastructure Supporting the Rework System

As in any manufacturing plant there are several layers of Business Information Systems. They communicate with each other to transmit numerous transactions and coordinate their work. The diagram below shows the systems involved in the rework process.

Figure 3: General View IT structure for the manufacturing plant in study.

Supporting Systems
Tracing Systems
Integration Systems



Each system plays a part, and to better understand the significance of each we consider their relation to the rework process and their characteristics:

Enterprise Resource Planning: this is the highest level of the firm's business information systems. This software has the greatest scope of control on the manufacturing activities, and works by getting updates from retailers on customer demand, which creates a demand "trigger" that forecasts the right product mix needed. The software also takes into account the delivery schedules of raw materials and production cycles.

Rework pieces could exist in the plans as a raw material although they are not currently included as such. They rather exist as Process Order (PO) by-products. These by-products are automatically created, updated and deleted following the rework process by inter-system transactions generated at Inventory Management and the Material tracking software and transmitted by the Integration Framework – see below. Enterprise planning is central to the rework process as it holds crucial tracing information such as the relationship between product batches and raw and rework material – the latter as by-products. In other words, the ERP system is the main beneficiary of the rework system itself. From this point of view, this software layer can be classified as a tracing system: it does not support the rework operational procedures, but gathers vital information from them to support other relevant processes such as product recalls.

Inventory Management system (module): the interface between ERP and IM is the most relevant to the rework process. The rework exists in IM as a by-product of a Process Order as quantity measured in Kg. IM keeps SKU-level information about product existences, raw and rework materials. This information includes quality, type, quantity (normally weight), location, cost, value, date code, freshness date, and propensity to depreciate or perish, among other characteristics. This system can also be classified as a tracing system under the current rework system: decisions are made by humans and in no way supported by automated systems such as the IM. For example, operators may decide where to store the rework pieces and inform the system afterwards, as opposed to some inventory management systems which support storing operations by providing detailed location information aiming at optimising space and improving efficiency in the put-away and recovering activities.

Material tracking system and Integration Framework: the Material tracking system and the Integration Framework constitute a middleware layer developed by the firm in conjunction with external consultants. The Material Tracking software is a generic application used at all manufacturing plants that use scanning technology; it enables the identification of stock by barcode scanning and is able to send transactional data to the ERP system. Both systems act as a complete integration layer allowing shop floor systems to communicate through one queuing messaging and interface layer. In effect the integration with the ERP system is only conducted between the Material tracking system – the Integration Framework and the ERP system rather than between all lower level systems and the ERP. Combined they also add a layer of redundancy into the systems protecting upstream and downstream information systems from downtime. Finally, the material tracking system allows writing "business logic" which is in effect, a series of programs that allow interpretation and matching of events in the shop floor as business occurrences. This matching is the major contribution made by these systems to the rework system. The material tracking system overlaps some ERP functionality in which it stores information on product bill of material (BOM) – including the rework pieces. It can be classified as a tracing system for it does not support operational activities but tracks them. The Integration Framework system is an exception to the "Use Case Approach" classification, for it is neither a tracing nor a supporting system. This system translates but neither stores nor provides information about the rework system.

The scanning applications: PLC and SCADA systems are all shop floor systems used to extract data from the line and take actions accordingly. These systems gather manufacturing events and convey them to the material tracking system and Integration Framework to be provided with business meaning. They also provide some support to the manufacturing operation by controlling manufacturing equipment. For instance, PLC decides and administers the desired quantity of rework in the vessel (see 2.3.3).

2.3. Processes Details, Use Case Diagrams and Flow of Events

This section reviews the main sub-processes constituting the rework system, and their details, diagrams and flow of events. It follows Timothy Milne's "Sub Group and Use Case Focus Group Methodology" (November 2002) to achieve a clear, standard and organised documentation.

2.3.1. Rework Creation

The "out of spec" rework items are collected into tubs [2] at set points along the manufacturing line. When these tubs are full they are placed manually into cages[3] by the operator. Each cage has an individual barcode identifying it. At the end of a shift or process order the line operator scans the cage using a handheld bar-code scanner and enters the number of full tubs present through a gui [4] on the same handheld device – PDA.

2 Tubs are plastic with capacity for approximately 16kg of rework when full
3 Rework Cages can fit 48 tubs
4 The Graphical User Interface is through a LCD touch-screen on the handheld scanners

The rework creation process has the following characteristics:

Table 2: Rework creation characteristics

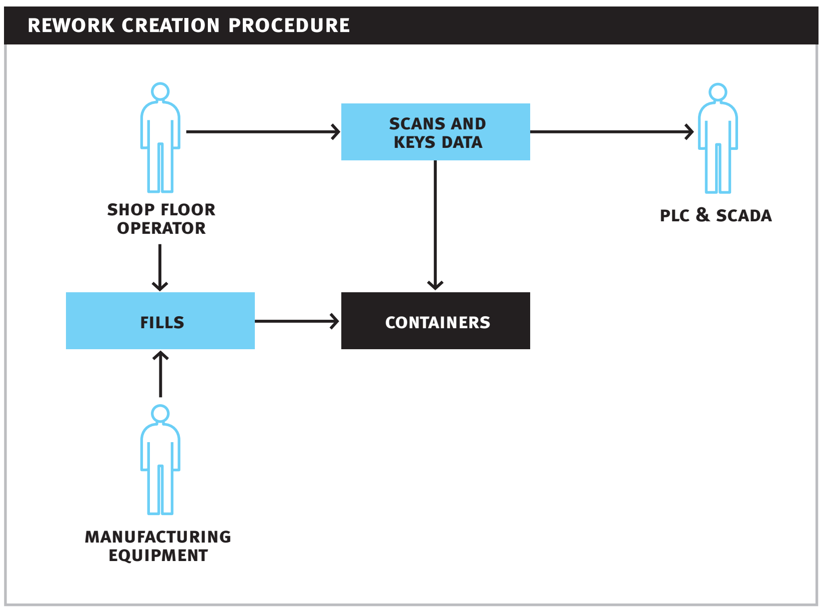
REWORK CREATION	
Actors	– Shop floor operator – Manufacturing equipment
Procedure steps	– Bowls or tubs filled to average weight – Bowls or tubs stacked in cage – When cage full, remove, scan and enter number of bowls or tubs – When production shift or end of process order, scan and enter number of bowls or tubs
Product flows	– From diverse points of the manufacturing process to the rework containers

Continuation of Table 2

REWORK CREATION	
Information flows	– From the shop floor to the information systems in terms of: – Identification of rework containers – tubs, cages – Number of elements per cage – bowls, cages – Rework characteristics
Level of automatism	– Low, except for tracing. Information systems only gather information from this process, which is mostly manual – rework handling
Decision points	– When to change cage
Contingency plans	– N/A
Supporting assets	– Information systems (PLC, SCADA system) – PDAs – Tubs and cages

Use Case diagram for the rework creation procedure under the current situation (non-Auto-ID-enhanced):

Figure 4: Use Case diagram for the rework creation procedure



Main flow of events

M.1. Manufacturing equipment
- M.1.1. Generates surplus by-products

M.2. Shop floor operator
- M.2.1. Fills bowls or tubs to standard weight
- M.2.2. Stacks bowls or tubs in cages
- M.2.3. If cage full, shift or production ends, scans bowls, tubs and cages tags and enters quantity

M.3. PLC and SCADA system
- M.3.1. Gather rework scanned information
- M.3.2. Transmit this information up to the Material tracking system and Integration Framework

2.3.2. Rework Movement and Storage

When a cage is full the operator will decide what to do with it. There are six possible destinies:

1. The rework piece is used immediately if demand exists,
2. The piece is temporarily stored on the shop floor [5],
3. the cage is stored for future rework,
4. it is moved to the company shop for sale,
5. it is sent to animal feed or
6. it is disposed of.

5 It is not always practical (or desirable) to move the rework from the shop floor into store – there may not be the available staff, it may be "planned" to be used in the next order, etc. A fixed FIFO method would not be adhered to, there needs to be an option of selecting newer rework than the system would recommend, with suitable warnings and cost implications, etc.

The choice depends on the level of damage of the aggregate pieces in the cage, the space available for storage, and the current rework demand. As long as it does not compromise product quality or violate regulations, it is most economical to send the rework for reuse since expensive chocolate is recovered. The operator enters the transaction into the information systems by first scanning a barcode that represents the destiny and subsequently scanning the cage. The operator is then in a position to move the cage to its destination.

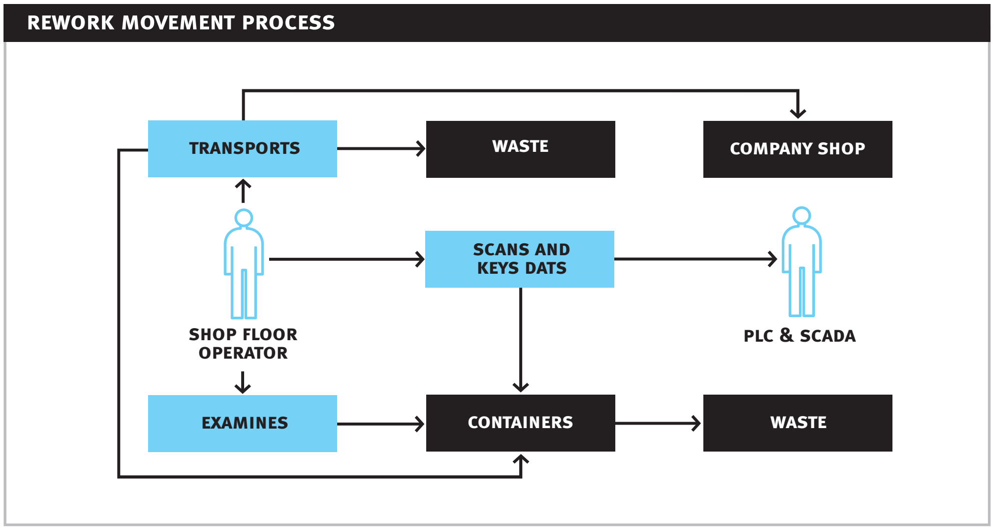
The rework movement process has the following characteristics:

Table 3: Rework movement characteristics

REWORK MOVEMENT	
Actors	– Shop floor operator
Procedure steps	– Examine rework contents – Decide what to do with the rework – Transport the cage to the corresponding place – In case of storage, decide location within the warehouse
Product flows	– From the shop floor to the warehouse, company shop, animal food line, or disposal facilities
Information flows	– Cage id and destiny – Product quality and other characteristics – In case of storage, cage location
Level of automatism	– Low, except for tracing. Information systems only gather information from this process, which is mostly manual – rework decision and movement
Decision points	– Cage destiny – Location within the warehouse
Contingency plans	– N/A
Supporting assets	– Information systems (PLC and SCADA system) – PDAs – Cages, bowls and tubs – Warehouse

Use Case diagram for the rework movement process under the current situation (non-Auto-ID-enhanced):

Figure 5: Use Case diagram for the rework movement process.



Main flow of events

M.1. Shop floor operator
- M.1.1. Examine rework pieces
- M.1.2. Decide rework fate
- M.1.3. Transports rework to destination
- M.1.3. In case of storage, decides location

M.2. PLC and SCADA systems
- M.2.1. Gather rework scanned information
- M.2.2. Transmit this information up to the Material tracking system and Integration Framework

2.3.3. Rework Reuse

The operator attempts to keep the rework vessel loaded. When the level of this vessel is low the operator selects a cage from the store and scans the barcode that represents use of rework (situated on the rework vessel) then the cage barcode. The information system conducts a check for any embargo on products associated with the cage and advises the operator through the handheld scanner interface. This check constitutes one of the few points in the whole rework system in which information systems act as process supporters as opposed to process tracers. The rework vessel itself is controlled by PLC and pumps the desired quantity of rework into the production process.

The main characteristics of this procedure are:

Table 4: Rework reuse characteristics

REWORK REUSE	
Actors	– Vessel operator
Procedure steps	– Check rework level in vessel – Decide re-fill – Pick-up a rework piece in the warehouse (keeping a FIFO approach as possible when necessary) – Check for embargoes – Transport and feed the rework vessel

Continuation of Table 4

REWORK REUSE	
Product flows	– Rework pieces from the warehouse to the rework vessel – In case of embargoes, from warehouse to disposal
Information flows	– Identity of chosen rework piece – Embargo flag
Level of automatism	– Medium: the system checks for embargoes, although the rework picking-up, movement and reuse activities are manual
Decision points	– Based on consumption, change the rework feeding pieces
Contingency plans	– N/A
Supporting assets	– Information systems (PLC and SCADA system) – Rework vessel – Warehouse – Tubs, bowls and cages – PDAs

Use Case diagram for the rework reuse procedure under the current situation (non-Auto-ID-enhanced):

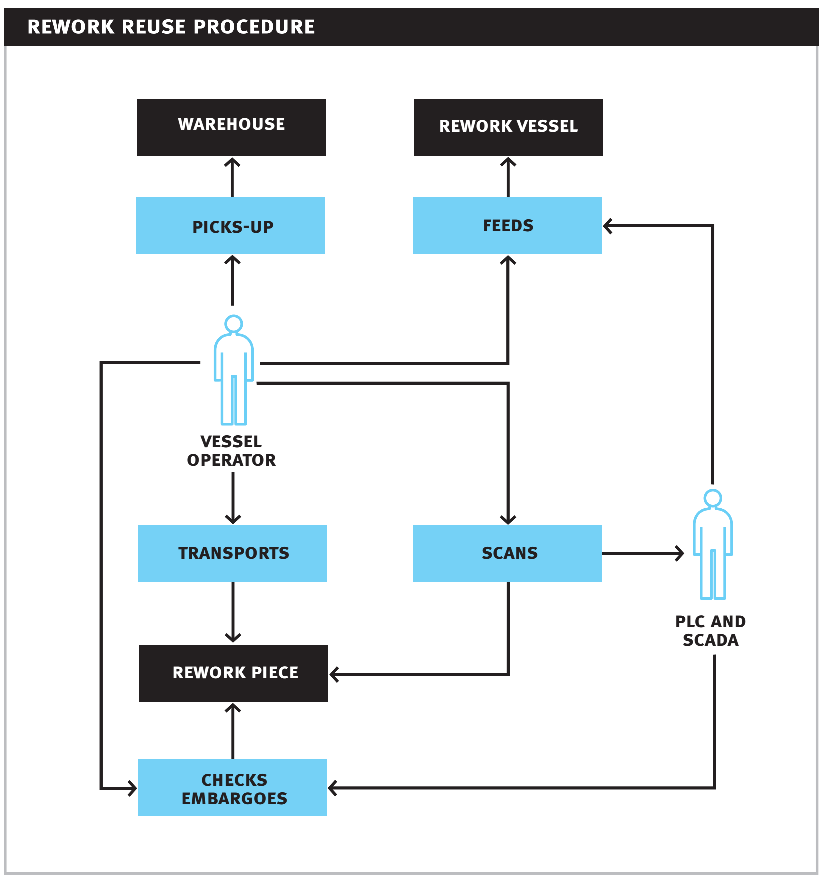


Figure 6: Use Case diagram for the rework reuse procedure

Main flow of events

M.1. Shop floor operator
  M.1.1. Monitors rework vessel input levels
  M.1.2. Picks up rework pieces
M.2. PLC and SCADA system
  M.2.1. Check and alert for embargoes
  M.2.2. Gather rework scanned information
  M.2.3. Transmit this information to the Material tracking system and ERP system
M.3. Shop floor operator
  M.3.1. Transports rework to vessel
  M.3.2. Feeds vessel

2.4. Limitations of Current Technology

The current available technology limits the possibilities in the aforementioned processes.
Some of these limitations are:

Scanning barcodes require manual intervention: the technology currently used is barcode-based, and requires operators to carry PDAs and scan tubs, bowls and cages whenever handling them. This implies extra-work and is cumbersome as operators need their hands to handle the products themselves. Current traceability and identification method provide some of the required financial reports but places an administrative burden on production staff.

Use of barcodes increases propensity to errors: when operators are in a hurry, or get distracted, the first duties to suffer are those related to administrative issues. Operators tend to undervalue administrative work as they do not directly see their results and benefits, but carry the burden of their execution. Barcodes can also fade, become damaged or become stained – especially due to raw material spills, making their scanning difficult or impossible. Stopping an ongoing rework operation or the corresponding manufacturing operation just because of an unreadable barcode is unthinkable, so the tracing information becomes incomplete in these cases.

A tracing-oriented system increases propensity to errors and creates distress and dissatisfaction in operations staff: detecting on-the-fly omissions and mistakes in rework scanning and related data is difficult as the whole current rework system is tracing-oriented. Events are normally triggered by programmed operator actions, which may be omitted or wrongly performed. Although resulting errors may be eventually detected by posterior analysis, they translate into poor and unreliable tracing information. Moreover, by the time they are detected it may be too late to undertake the pertinent corrective actions, as the involved rework pieces have most likely been used or disposed. Consequently, this system is liable of creating strong tensions between operators and managers, as it makes it very easy to “find the guilty” and blame operators in case of mistakes, but does little to help avoiding them. In a nutshell, outdated information on operational mistakes is only useful to blame, but not to rectify – at least in the short term.

Systems do not properly reflect rework needs and usage in production recipes: Process orders are set up to produce “standard” product, although waste is expected and therefore allowed for in budgeted product costing etc. It does not show up in plans for creation (e.g.: loss against the current process order) or consumption (positive variance against the order in which it is used) although it does appear as a nominal item (1 gram) on the bill of materials (BOM). This was due to the onerous level of administration of the ERP system

2.5. Opportunities and Issues to Solve or Improve

Reduction of manual intervention. The full automation of rework tracking and tracing procedures reduces the need for human work and intervention. Operators will have "free hands and minds" to focus on their work without worrying about performing administrative actions.

Support of rework operational activities and decisions. As explained in section 2.4, one of the problems with the current tracing-oriented system is that it provides none or little support to ongoing operational activities. Supporting operational activities is important as to reducing mistakes. The system could not only monitor rework activities, but also provide operators with feedback, warnings and valuable decision information when necessary. Moreover, some common decisions such as where to store rework pieces or which one to reuse could be automated in order to improve immediate or future operations such as reducing storage and recovery time in the warehouse. More than passively survey operations, information systems should dialog with operators to provide support and advice.

Rotation improvement. Rework stored in the warehouse[6] is currently stored ad-hoc for there is no pre-defined way of storing the rework. As a result operators must search through the rework store to find cages with the oldest rework in for reuse. This does not always occur and consequently rework is not used in a FIFO approach, leading to outdated items getting "lost" in the store and being wasted[7]. However, the current rework system and reports assume perfect rotation, which means that rework pieces move in the same order within the recycling loop and no overtaking takes place. Using the information stored in information systems to support the picking up of rework pieces can ensure perfect rotation as rework pieces with the earliest due date are easily found. Achieving perfect rotation in warehouse rework access is important as it directly impacts on product quality and level of waste – see below, "reduction of waste".

Improvement of product recalls. Having more and more reliable information on rework pieces and their usage in the manufacturing process allows for the reduction of the recall window's time and volume. Product recalls are important as they involve massive movement of goods and must be done properly to avoid legal consequences or brand damaging. Moreover, after September the 11th, governments in the developed world increased their concern on food recalling systems. For example, in the US, "The federal government has signalled its intent to increase its regulatory role in the Nation's food supply" (Huffman, 2002). In the UK, the topic is especially important after the BSE and e-coli outbreaks not too long ago.

Better rework monitoring. Being able to monitor rework creation, handling and usage allows detecting below-average operations such as abnormal rework generation per production line or employee, or excess rework wastage, and above-average operations. This will in turn help identifying best practices and homogenising manufacturing quality, which is important not only to reduce costs, but also to ensure product quality and make the best possible use of the manufacturing assets.

Reduction of waste. Waste in the manufacturing process can be reduced for the following reasons: first, an imperfect rotation is always a source of waste as some rework pieces reach their expiration date not because of the lack of demand, but because they are merely left behind in the process. Second, a more precise recall window will reduce the amount of saleable product that has to be returned and disposed of. Third, monitoring rework will help detecting and reducing abnormal levels of it result from defective machines, out of spec raw materials, or out of control processes. Reducing waste is important not only because of the cost reduction it involves in both the cost of material and disposing procedures, but also due to environmental concerns and regulations.

6 Storing all rework pieces in the warehouse may not always be desirable: time can be lost travelling to the store when rework material may be readily available alongside the plant. As long as the rework is in-spec it will not compromise quality, cost is the remaining issue, it may be more cost effective to use the material on hand, if the travelling time is too large.

7 In fact some waste may go to animal feed but there are increasingly strict rules surrounding this.

2.6. Auto-ID Capabilities Enhancing the Use Case

The main Auto-ID capabilities enhancing the Use Case are:

1. Tracking and identification capabilities to improve the rework creation, movement and reuse processes. The ability to automatically identify and track a rework piece in the very moment of its creation and during its life makes Auto-ID a remarkable technology to improve the whole rework system in order to achieve reduction of manual intervention, support of rework operational activities and decisions, perfect rotation, rework monitoring, and reduction of waste. An important opportunity is related to the automatic tracing capabilities in improving rework monitoring, for the triggering of feedback, advices, warnings and corrective actions will switch from operational actions – current schema – to automatic surveillance by means of Auto-ID. As mentioned in 2.4, the current system can only trigger these actions as long as operators follow some programmed scanning and data entry steps. Otherwise the system is unable to support operations as events happen unnoticed to it or are detected too late – this is considered the major flaw of the current process and technology.

2. Tracing capabilities to improve the reuse process. Having the possibility of tracing back a rework piece allows picking up the right one. It also allows for the detecting of embargoes. Improving the reuse process would in turn achieve more support of rework operational activities and decisions, improvement of product recalls and reduction of waste.

The following table summarises the relationship between current processes, opportunities and issues to solve, and the Auto-ID capabilities leveraging these opportunities:

Table 5: Opportunities of improvement, processes and Auto-ID capabilities leveraging them

	CREATION	MOVEMENT	REUSE
Reduction of manual intervention	Tracking	Tracking	Tracking
Support of operational activities & decisions		Tracking	Tracing
Perfect rotation enabling		Tracking	Tracing
Improvement of product recalls			Tracing
Better rework monitoring	Tracking	Tracking	Tracking
Reduction of waste	Tracking		Tracking & Tracing

2.7. Implementation

In this section we review some implementation pre-requirements, details and alternatives, although avoid going through a complete implementation plan as it is not the intention of this study. We focus on those implementation characteristics with the highest impact on existing procedures and information systems, such as integration characteristics, technology layout – location of readers and tags, and some relevant technical considerations such as refresh rate and reading accuracy.

2.7.1. Implementation Pre-requirements

Reader and Savant™ Filters and counters: in the scanning and capture of EPC™ in this use case, it is assumed that the lists of EPC™ may be summarized as aggregate counts of items – e.g. EPCs™ of tubs in a tagged cage. This will reduce the burden on the system by eliminating superfluous data; the theory of filtered counts is outlined in the background document entitled Standard Reader/Savant™ API, Filters & Counters being prepared by the Auto-ID Software Action Group – not published yet.

Integration must be bidirectional: as mentioned in 2.5, one of the issues to improve is the nature itself of the rework system. It can be transformed from merely a tracing system to a tracing-supporting one. This could be done without Auto-ID, although this technology eases the conversion for it transparently monitors rework activities and does not depend on the actions of operators to gather information and trigger advices or warnings. This new approach requires the PLC/SCADA system «Material tracking system/Integration Framework» ERP system interfaces to be bidirectional, as systems will provide new transactions to support rework operations and decisions. In brief, supporting transactions will flow from top to bottom (digital to physical world), as opposed to tracing information which travels the other way round.

Queries: an interface is needed to allow queries to be made as to rework pieces details (e.g. location, contents, quality, due date, source batch etc). This interface must also be present on the handheld devices to provide full functionality when handling rework.

Scan reliability: 100% scanning accuracy needs to be guaranteed. The location of readers and/or fixed tags assumes that products at item level can be read when they are being moved passed readers at various speeds.

Refresh Rate: as to the rework system, what maters are dynamic changes. Transactions should be generated only when a rework piece is moved. Dynamic changes are intrinsically related to decisions. For example, in rework creation is the cage put-away process that triggers the verification and classification of its contents, and generates the related tracing data. The refresh rate should allow for the detection of all dynamic changes. That is, pooling cycle should not exceed the dimension of the space covered divided by the maximum object speed and should allow for some margin to guarantee 100% scanning accuracy.

2.7.2. Implementation Alternatives

There is more than one implementation possibility when using Auto-ID to improve the rework system. The implementation possibilities are mainly given by the number and location of readers within the shop floor – or that of fixed tags in case of mobile readers. Configurations may be as simple as putting one reader in the rework warehouse door plus a terminal to interact with the operator; or as complex as having readers wherever a rework piece is created, stored, used and even in strategic corridors, plus terminals wherever any rework data is collected or rework decisions are made.

As opposed to number and type of readers, tag location and type are not believed to have an important impact on the cost of implementation alternatives for they will not experience continuous renovation. These are low, fixed costs. In the implementation alternatives we propose, all tubs, bowls and cages are assumed to be tagged with passive chips, although active chips are also a possibility.

This paper proposes the following implementation approaches:

a) Low cost alternative.
   - Fixed reader(s) and terminal(s) in the rework warehouse exit(s)

Under this approach, only the movements to and from the rework warehouse are monitored, and operators are expected to supply information on new rework pieces such as content, quality date of creation etc; and to maintain a tidy rework system within the shop floor (e.g. not to misplace empty or full rework containers or delay their transportation). Information systems will be able to gather tracing information by relating operators' data with the rework identification and date of creation and reuse, and with production batches. This approach will allow for tracing but not for supporting the rework system, and will mainly support the rework movement process. Accuracy on tracing rework creation and reuse data will still depend on operators' input. Nevertheless, this approach may help achieving full traceability and enable perfect rotation.

b) Medium cost alternative.
- Fixed reader(s) and terminal(s) in the rework warehouse exit(s)
- Mobile readers attached to wireless PDAs with GUIs
- Fixed tags in every rework creation and reuse point
- Fixed tags in strategic aisles where rework pieces have to pass through.

This approach combines the advantages of the previous one, yet adds the possibility to scan, enter or retrieve information in the rework creation, movement and reuse activities via PDAs. It saves costs because readers are mobile and location information is provided by fixed inexpensive tags strategically located in different places in the shop floor. This approach assumes that operators will always carry PDAs and mobile readers while transporting and handling rework containers and pieces, and that the latter do not move without human intervention. It allows not only for rework tracing and monitoring, but also for decision support as PDAs would warn of mistakes or provide advice on operational activities on-the-fly. Manual intervention will be also reduced as all the scanning activities will be automatic and transparent. Operators will only have to enter information such as rework content, quality etc.

c) High cost alternative.
- Fixed reader(s) and terminal(s) in the rework warehouse exit(s), strategic aisles and rework creation and reuse points.
- Smart shelves on rework warehouse OR
- Mobile readers (less expensive)

This approach is the most sophisticated and expensive one. It eliminates the need for mobile readers (wireless handheld devices) and their associated manual procedures. It is better than the previous because operators do not have to carry any equipment and only enter information on rework quality and content whenever a rework piece is created. This alternative allows reducing manual intervention, supporting operational activities and decisions, and enabling perfect rotation. It also helps putting away and retrieving rework pieces from the warehouse, for rework pieces are constantly monitored via smart shelves.

2.8. Potential Benefits

In relation with the improvement opportunities, the main benefits that result from an improved rework system are:

Productivity increase: by keeping a tidier rework environment, the manufacturing process will make the best possible use of rework storing facilities and handling assets. The following improvement opportunities directly or indirectly help increasing productivity:

- **Reduction of manual intervention**: employees will be freed from administrative tasks.
- **Support of rework operational activities and decisions**: better decisions will imply a better use of human and other resources
- **Better rework monitoring:** best practices will be easily identified and exported to less productive lines.

The productivity increase result from all these improvement opportunities can be easily valued using cost/benefits analyses, so long the inputs are known. For example, the productivity increase result of exporting best manufacturing practices can be measured by the difference in average cost per good between the best and the under-performing manufacturing lines.

Cost reduction: it comes from various improvement opportunities.

- **Perfect rotation enabling**: reducing waste from expired rework pieces
- **Reduction of waste**: this allows for saving not only the cost of disposed material but also that of disposing procedures
- **Reduction of manual intervention**: which may be expensive
- **Improvement of product recalls**: which will require far less resources as requested products will be easily identified and found.

Valuing these benefits in terms of money implies a straightforward cost/benefit analysis in some cases such as reduction of manual intervention; but a more complex one in others where the inputs are not known such as reduction of waste result from perfect rotation; for waste may result from both lack of demand and product left-behind. In the latter, some stochastic valuation techniques may be necessary.

Strategic value: there are two main sources of strategic value. First, the brand and company's name will benefit from better product quality and reliability, and the company will be able to leverage them as competitive advantages. Second, the Auto-ID infrastructure has strategic value as long as it can be used for other applications, either immediately or in the future. For example, mobile readers in the shop floor could be used to gather information on equipment and their maintenance and on quality control activities. Strategic value can be estimated in terms of money by using complex financial formulae as real options or the like, but that is out of the reach of the current paper.

3. ASSESSING THE IMPLEMENTATION IMPACT

3.1. Identifying the Affected Systems and Related Data and Transactions

In this section we will identify the impact of Auto-ID on the described procedures of the rework system and their related information systems. The impact is found by matching the decision points within them with the information affecting those decisions and related transactions, as well as the information flows from the procedures to the supporting information systems. Table 6 summarises the analysis:

Table 6

INFORMATION SYSTEMS, DECISIONS AND SUPPORTING DATA

	Procedures	Creation	Transport		Reuse	
Systems	Decisions/ activities Transactions	Rework creation	What to do with the rework?	Where to store the product?	Where to find next piece?	Is there any embargo?
PLC and SCADA system	Piece identification Rework characteristics	Scan Data entering	Scan Data entering	↑		↑
Material tracking system	Association with production batch	Scanning date	Rework fate	Preferred location		Embargoed reworks
ERP	Tracing information	Production batch				Product recalls

As the current rework system is mainly tracing-oriented, most of the decisions are made by humans and feed to the systems – information flows are horizontal in table 6. The only exceptions are the embargo detection and the preferred storage location – which data flows are illustrated by the arrows.

3.2. New operational Procedures with Auto-ID

As table 6 shows, many transactions and pieces of data flowing between operational procedures and information systems deal with rework identification and tracing – (what rework pieces exist, when were them created and what path have they followed?).

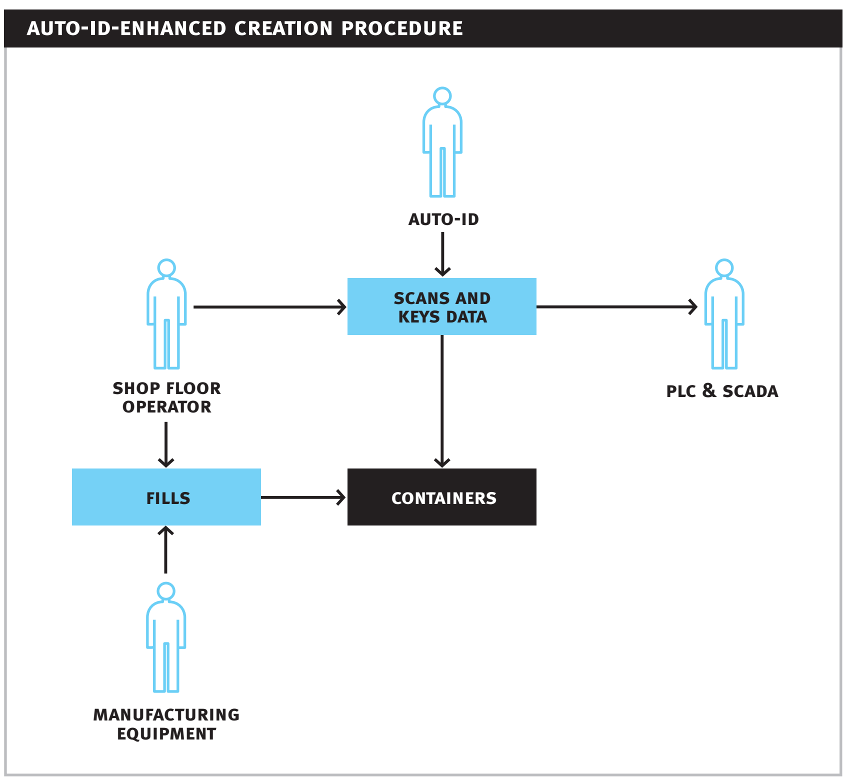
A particularly case is the material tracking system, which stores information on rework creation, quality, general characteristics, fate, and supports the reuse by warning on embargoes.

The impact of Auto-ID on current procedures involves the inclusion of a new actor – Auto-ID infrastructure, which will provide information about rework identification and location and get information directly from the physical world. This new actor was included in the Use Case diagrams to properly reflect the impact, as shown below. The respective procedure steps also reflect the extra or modified steps.

3.2.1. Creation Process

Auto-ID will provide valuable information on new rework pieces as they are created. Depending on the implementation alternative, the removal of rework containers from the sites where surplus by-products are generated will trigger an automatic rework creation transaction (implementation alternatives B and C). In the implementation alternative A, the rework creation transaction will be generated upon material receipt at the warehouse door, and operators will have to provide the system with rework related characteristics. The following diagram shows how the new actor fits into the existing procedure.

Figure 7: Use Case diagram for the Auto-ID-enhanced creation procedure



Main flow of events

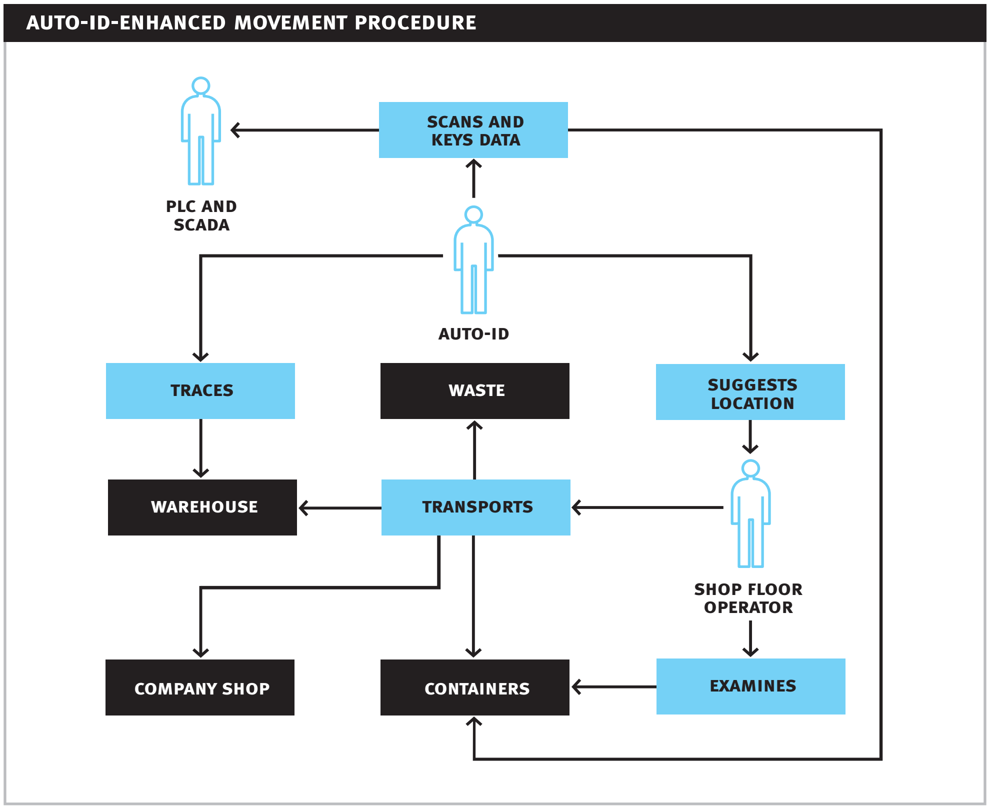
IMPLEMENTATION ALTERNATIVE A:
A.1. Manufacturing equipment
    A.1.1. Generates surplus by-products
A.2. Shop floor operator
    A.2.1. Fills bowls or tubs to standard weight
    A.2.2. Stacks bowls or tubs in cages
    A.2.3. If cage full, shift or production ends, move it out
A.2. PLC, SCADA system and Auto-ID
    A.2.1. These systems do not intervene as the rework creation is made at movement time

IMPLEMENTATION ALTERNATIVES B AND C:
A.1. Manufacturing equipment
    A.1.1. Generates surplus by-products
A.2. Shop floor operator
    A.2.1. Fills bowls or tubs to standard weight
    A.2.2. Stacks bowls or tubs in cages
    A.2.3. If cage full, shift or production ends, move it out
A.3. Auto-ID
    A.3.1. Detects cage movement and alerts PDA to ask for details
A.4. Shop floor operator
    A.4.1. Enters reworks characteristics such as content, quality etc
A.5. PDA
    A.5.1 Registers reworks characteristics and send them to PLC and SCADA system
A.6. PLC and SCADA system
    A.6.1. Transmit this information up to the Material tracking system and Integration Framework
A.7. Auto-ID
    A.7.1. Verifies that product is transported to destination, and warns otherwise

3.2.2. Rework Movement

Auto-ID will receive information on rework pieces movement and storage. Under alternative A, both the creation and movement processes are traced together and the system relies on operators' information to complete them. Under alternatives B and C, readers of fixed tags in aisles and warehouse entrances and exits generate the necessary rework movement transactions to the tracing systems. Auto-ID will also enhance the movement process by allowing the systems to suggest an available storage location. The latter applies to all implementation possibilities – A, B and C; but only C guarantees that the location is really available for it can rely on smart shelves' information. Using Auto-ID to trace and support the movement of rework pieces involves considering it as a completely new actor. The following diagram shows how this new actor fits in the existing procedures:

Figure 8: Use Case diagram for the Auto-ID-enhanced movement procedure



Main flow of events

A.1. Shop floor operator
- A.1.1. Examine rework pieces
- A.1.2. Decide rework fate
- A.1.3. Transports rework to destination
- A.1.4. In case of storage, queries the PDA for an empty location

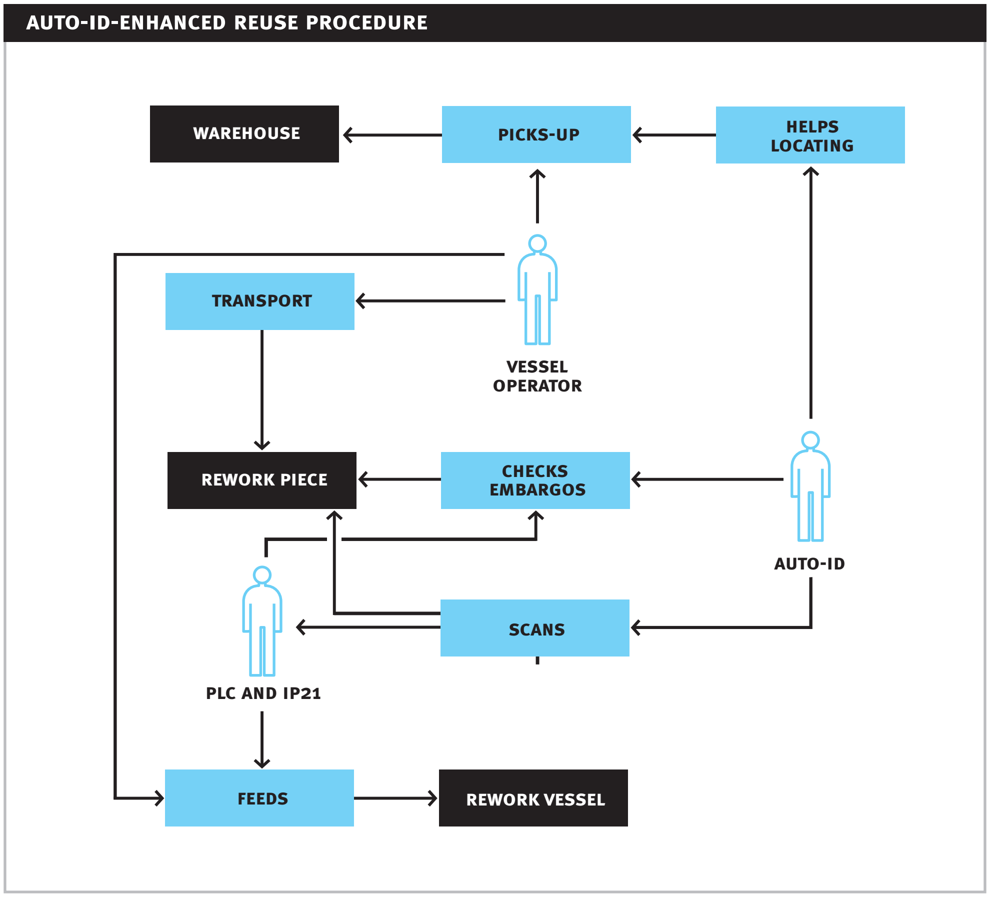
A.2. Auto-ID
- A.2.1. Finds an empty location for the rework piece (only implementation alternative C)
- A.2.2. Traces rework piece as it is moved to the warehouse (only implementation alternatives B and C)
- A.2.3. Traces rework piece as it enters the warehouse and is stored
- A.2.4. Traces rework location
- A.2.5. Based on rework piece tracing information, gets production batch
- A.2.6. Informs PLC and SCADA system of the rework identity, location and storage date

A.3. PLC and SCADA system
- A.3.1. Transmit this information up to the Material tracking system and Integration Framework

3.2.3. Rework Reuse

The Auto-ID infrastructure provides a reliable infrastructure to find rework pieces in the warehouse and guarantee perfect rotation, even in case of losing detailed location information on rework pieces. Moreover, when operators take rework pieces out of the warehouse, the Auto-ID technology can automatically check for embargoes or inconsistencies such as missing or mixed tubs and alert them. Transparency in the scanning process allows operators to pick and use whatever rework piece they think they need. The Auto-ID infrastructure will silently check for evident or possible mistakes and intervene only when necessary. The following diagram shows how the new Auto-ID actor fits in the reuse process:

Figure 9: Use Case diagram for the Auto-ID-enhanced reuse procedure



Main flow of events

IMPLEMENTATION ALTERNATIVES A AND B:

M.1. Shop floor operator
- M.1.1. Monitors rework vessel input levels
- M.1.2. Picks up rework pieces

M.2. Auto-ID
- M.2.1. Verifies rework piece as it leaves the warehouse
- M.2.2. Informs of transaction to PLC and SCADA system

M.3. PLC and SCADA system
- M.3.1. Check and alert for embargoes
- M.3.2. Check for imperfect rotation
- M.3.3. Gather rework scanned information
- M.3.4. Transmit this information to the Material tracking system and ERP system

M.4. Shop floor operator
- M.4.1. Transports rework to vessel
- M.4.2. Feeds vessel

M.5. Auto-ID (alternative B only)
- M.5.1. Verifies that rework piece is actually fed into the vessel, and warns otherwise

IMPLEMENTATION ALTERNATIVE C:

M.1. Shop floor operator
- M.1.1. Monitors rework vessel input levels
- M.1.2. Picks up rework pieces

M.2. Auto-ID
- M.2.1. Helps locating right rework piece
- M.2.3. Verifies rework piece as it leaves the warehouse
- M.2.4. Informs of transaction to PLC and SCADA system

M.3. PLC and SCADA system
- M.3.1. Check and alert for embargoes
- M.3.2. Check for imperfect rotation
- M.3.3. Gather rework scanned information
- M.3.4. Transmit this information to the Material tracking system and ERP system

M.4. Shop floor operator
- M.4.1. Transports rework to vessel
- M.4.2. Feeds vessel

M.5. Auto-ID
- M.5.1. Verifies that rework piece is actually fed into the vessel, and warns otherwise

3.3. Impact of New Procedures on Existing Information Systems

In this section we analyse the main changes that existing information systems must undergo in order to leverage Auto-ID capabilities. These changes cover new storage requirements (Auto-ID will use and generate new data that must be stored somewhere); new transactions (systems will extend their functionality and have to exchange the new Auto-ID-generated transactions); and new reports (this new information gives place to new analysis possibilities).

3.3.1. Shop Floor Systems (PLC and SCADA System)

NEW TRANSACTIONS

Location information: for both the rework storage and recovery procedures in the warehouse, operators' PDAs should display availability or location respectively. This information will come from the material tracking system, but should be part of PLC and SCADA system as these systems are responsible for the interaction with operators. This new transaction is support-oriented, and in the case of implementation alternative C, it does not imply entering information as the Auto-ID platform will automatically detect ad-hoc location decisions.

Imperfect rotation warning: during the reuse process, these systems will alert any takeover when picking up rework pieces. This information will come from the material tracking system as this is the system storing rework pieces details such as creation date, but will be shown via operators' PDAs.

Embargo and aggregation warnings: similarly to the current approach, PLC will warn on embargoes whenever a rework piece is taken out of the warehouse for reuse. Furthermore, whenever a cage is scanned after its creation, the system will check for consistency in their aggregation, verifying that the cage contains all the original tubs or bowls, and warn of any discrepancies. The PLC and SCADA system will have to consider these warnings in their user interfaces.

Rework pieces details: in implementation alternative B, PDAs will automatically display relevant details on rework pieces when in proximity. In alternatives A and C, these details will be shown in fixed terminals next to the readers. The PLC and SCADA system need more logic to allow showing and even updating some of these details.

3.3.2. Manufacturing System (Material tracking system)

NEW STORAGE REQUIREMENTS

Location information: the material tracking system will need to store detailed location information of rework pieces within the warehouse. This will ease and speed up the recovery, and minimise trips when storing and recovering rework pieces. Location information does not have to be limited to the warehouse: in alternative C, rework pieces will be identified and located in the creation places, before they are moved to the warehouse. This will allow controlling creation time and detecting mixed rework pieces result of two different production shifts.

Rework piece details: although the material tracking system already stores many rework pieces details, Auto-ID can provide even more data, such as the exact time and date when the rework piece was created. In alternative B, mobile readers will even identify the operator who created the piece.

Aggregation information: The material tracking system will store information on the aggregation between cages and their respective tubs and bowls. This information should be overwritten whenever a new piece of rework reused, emptied or created with different elements.

NEW TRANSACTIONS

Location information: this information will be automatically collected from the Auto-ID infrastructure and sent to the material tracking system: in alternatives A and B, this will be happen at the warehouse entrances and exits, whereas in alternative C, smart shelves will constantly monitor rework position in space. This information will be sent to the PLC and SCADA systems to be displayed on PDAs in case of product recovery upon request by the operator via a fixed or mobile terminal.

Rework pieces details: the Auto-ID infrastructure will automatically detect proximity of a mobile or fixed reader and rework piece, and automatically send this information to the related terminal (fixed) or PDA (mobile) via the PLC and SCADA systems. The material tracking system needs two transactions to perform this: one from the Auto-ID infrastructure reporting the detection of rework piece in a certain place; and other to PLC and SCADA system displaying its details.

Aggregating/disaggregating: these two transactions will allow establishing or breaking up the relationship between cages and their content – tubs or bowls.

Rework piece to use: the material tracking system should include a transaction indicating which rework piece to reuse for specific manufacturing lines and recipes. This picking algorithm can be as easy as a FIFO queue, or something more sophisticated such as a complex algorithm to avoid circular back-feeding, which consists on the recursive recycling of rework pieces in one or more manufacturing lines in such a way that a contaminated material cycles and contaminates many production orders.

NEW REPORTS

Rotation quality: this report will show the rotation quality in warehouse accesses by period and by rework type. Quality will be displayed as a percentage: 100% means perfect rotation or FIFO; and 0% means perfect LIFO.

Rotation quality is given by the following formula:

$$RQ = \frac{|P| - |POO|}{|P|} * 100$$

Where P = rework pieces, and POO = rework pieces out of order, calculated as:

$$POO = \{p_i \forall p \in P \wedge i \therefore \exists p_j \therefore O(p_j) < O(p_i) \wedge i > j\}$$

Where $O(p)$ is a function that gives the desired order of piece p – e.g. creation date.

The rotation quality report can be generated under any of the three implementation alternatives, although data from the first (A) may be inaccurate and unreliable for the Auto-ID infrastructure cannot control what happens beyond the warehouse boundaries. For example, operators may mistakenly swap rework pieces in the creation and reuse procedures.

Rework per line and batch: this new report will show the relationship between rework pieces and production batches by rework type and quality, aiming at comparing production rework generation and helping identifying best practices. For this work to be useful, manufacturing information such as batch size, product type, raw material quality and status of equipment would be needed. Production batches in different manufacturing lines can only be compared as long as the remaining variables remain the same or similar.

Warehouse misplacing: in the implementation alternative C, the Auto-ID infrastructure may help detecting and locating rework pieces placed out of their expected location by means of a report listing all misplaced rework pieces. This would help detecting and correcting wrong storing practices.

3.3.3. ERP System

NEW STORAGE REQUIREMENTS
One of the major impacts of using Auto-ID to improve the rework system in the ERP and IM is related to the fact that the ERP system does not treat rework pieces as such, but as manufacturing by-products. This means that relating rework pieces to manufacturing batches requires new entities, relationships and functionality. Similarly, the information about product recalls and their relationship to manufacturing batches, rework pieces, and raw materials should be stored within the ERP system. In a nutshell, the ERP system should include the following new elements:

Table 7

ERP SYSTEM NEW ENTITIES AND RELATIONSHIPS	
Entities	– **Rework pieces** – **Recall batches**
Relationships	– Batches – Rework pieces – Rework pieces – Raw materials – Rework pieces – Rework pieces – Recall batches – Manufacturing batches

Only by storing all this information will the ERP system be able to determine which batches to recall in case of rework cross-contamination. The relationship goes like this:

a) The contaminated manufacturing batches are those where the contaminated raw material was used.
b) The contaminated rework pieces are those generated in the contaminated manufacturing batches.
c) The recall batches are those that used the contaminated rework pieces.
d) Depending on the quality and safety policies and regulations, the recall batches window can be extended to those batches that used contaminated rework pieces result of contaminated batches, result in turn from previous contaminated rework pieces, and so on so forth until an acceptable dilution ratio is reached.
e) If dilution is not allowed at all, then the rework picking algorithm for reuse should be modified to avoid circular back-feeding. That is, rework pieces should not be used in the same manufacturing line they were generated or where their previous rework pieces were generated.

Some of these entities and relationships may be stored in the material tracking system instead, although we recommend developing it as the ERP system standard to achieve common inter-organisational way of dealing with the rework pieces. By doing so, rework pieces may be eventually traded and their related information exchanged using Auto-ID's inter-organisational capabilities – not considered in this paper for this study focused on the intra-organisational aspects of rework.

NEW TRANSACTIONS

Rework creation and reuse: these transactions are similar to the current ones. However, instead of being considered as ERP by-products, they are considered as re-work pieces. This makes a difference because under the current schema rework pieces stored as by-products have to be deleted when used, or updated as raw material, which reduces tracing possibilities. With a specialised, rework-oriented system, information on rework pieces does not have to be changed radically or eliminated, but their status updated following real changes. By doing so, historical information is accurately kept.

Rework embargo: the ERP system will generate information on rework embargoes to feed the material tracking system and allow for fast and safe detection of unusable rework pieces. This transaction may be triggered by raw material embargoes or upon user request. It will identify the rework piece to embargo by means of its EPC™, and indicate the reason for this embargo if known.

NEW REPORTS

Recall batches: given a defective or contaminated raw material, this report will follow the relationships explained above and report up to a desired degree of dilution (if any) the batches directly or indirectly contaminated. It will also report on the stored rework pieces that are contaminated to allow for fast and safe removal and disposition.

3.3.4. Interface System (Integration Framework)

Bidirectional transactions: hitherto, most of Integration Framework transactions related to the rework system are unidirectional. They collect information from the rework activities via barcodes and send it to the ERP system. This is all what is needed for a tracing system, although a supporting system would need bidirectional interfaces, as well as on-line, real-time transactions to support decisions. Integration Framework has to be tightly coupled with the Material tracking system, SCADA system, PLC, the ERP system and Auto-ID in order to be able to combine and interpret transactions and generate new ones.

Some of the transactions asking for bidirectional treatment include:

- Rework embargoes
- Rework details
- Location information

Interoperability: the Integration Framework system must be able to gather and combine information from many different sources in order to transform physical events in business events – rework transactions. Particularly, it must be connected to the Auto-ID infrastructure (Savant™, PML and ONS) and get and update information about rework pieces and their movements. Typical transactions include physical readings, aggregation of cages and their content, filter of undesired reads, and update PML with rework pieces characteristics should this information be shared at either the inter- or intra-organisational level.

4. CONCLUSIONS

One major finding of this study is that current information systems do not require significant changes to benefit from Auto-ID as we might initially think. An exception to this is the ERP system. Furthermore, the impact of the adoption of this technology is more qualitative than quantitative, and most processes remain more or less the same but use and provide more accurate and reliable results and information. The main changes can be summarised as:

1. Inclusion of the rework entities, logic and functionality in the upper level system (the ERP).
2. Improving the capabilities of the interface to route on-line, bidirectional transactions.
3. The location information must not only refer to warehouse shelves, but also to physical places within the shop floor where rework pieces are or may be temporarily stored.
4. Making the rework system more supportive to operational activities by transforming it from a tracing to a supporting system. This implies complementing Auto-ID with interactive technologies such as PDAs or computer terminals. Auto-ID will gather information from the physical world such as rework piece IDs and pieces location, whilst complementary user interfaces will gather and provide rework-related information from and to operators.

As we can see, the required modifications are relatively superficial, and do not involve dramatic functionality changes or extensions, except perhaps in the ERP system. Moreover, not all these modifications are essential to Auto-ID implementations. For example, some reports such as the one valuing perfect rotation are accessory.

For some applications like the one analysed here, a radical substitution of the installed information systems is not required in order to incorporate Auto-ID. It suffices to add functionality extensions and a sound integration middleware.

In line with previous similar works, the main conclusion of this study is that the nature and depth of impact on current procedures and information systems allow for incremental adoptions, even though Auto-ID is a disruptive technology. That is, as long as early applications allow for extensions, others can follow suit as Auto-ID and its complementary technologies become cheaper and more reliable, and the organisation incorporates and accepts them.

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