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Abstract

Although RFID is seen by many as a revolutionary enabler of automated data capture, confusion still remains as to how manufacturing organisations can identify cost-effective opportunities for its use. Managers view promotional business case estimates as unjustified, simulation based analysis and analytical models as secondary modes of analysis, and case studies are scarce. Further, there is a lack of simple tools to understand how RFID can help to achieve a leaner manufacturing environment, after the use of which practitioners can be routed to grounded forms of analysis. The purpose of this paper is to provide and test such a toolset, which uses the seven Toyota Production wastes as a template. In our approach, RFID technology is viewed as a vehicle to achieve leaner manufacturing through automated data collection, assurance of data dependencies, and improvements in production and inventory visibility. The toolset is tested on case examples from two push-based, multi-national fast moving consumer goods manufacturing companies. The opportunity analysis is shown to identify not only initially suspected areas of improvement, but also other areas of value.

Keywords RFID, lean manufacturing, automated data capture, visibility, lean, 7 wastes

1. Introduction

Using radio waves, RFID tags can transmit the identity of an object wirelessly, without human intervention. When appropriate information system architectures are fed with real time data on uniquely identified products visibility of operations can be increased by associating products with their current location, condition and history. The physical flow of products are synchronised with data flow at real time, eliminating human error from the data collection process. Granularity of data can be increased to item level, and data can be transformed into information by coupling RFID with sensory or other related data. RFID technology has found uses in a variety of manufacturing related applications in production automation and inventory management. Tracking of operations previously dependant on the operator to record data or perform barcode scanning operations, are automatically carried out. Inventory strategies such as first-in-first-out can be implemented automatically by drawing the attention of the operator as to which item should be used first. Automatically gathered location information reduces time and effort spent on manual stock counting. Operators can be informed about sample quality testing results on the work-in-progress batches. Other inventory management strategies such as just-in-time can be aided by using RFID as an electronic Kanban, triggering the pull based use of material. RFID can also help manage two types of manufacturing systems control environments: Conventional, and Distributed control. In conventional control systems, typical uses of RFID include data integration with material handling and production-control systems. By doing so, items in production can automatically be routed to the appropriate assembly, testing or packaging locations. In distributed manufacturing, uniquely identified products can drive their own production by pointing machinery to their specific production recipes.

Although RFID has found a wide range of applications in manufacturing, confusion still remains as to how managers should start looking for opportunities, and if RFID can help in achieving a leaner manufacturing environment. Part of the reason for companies' confusion is the lack of abundant case studies and exemplary work to which manufacturers can relate. Although analytical models or simulation studies from operations management exist, they are supply chain oriented, and are viewed as a secondary step in quantifying RFID's value. These observations point to a requirement for structured tools to help manufacturers identify opportunities where RFID can help, addressing the question: does RFID present an opportunity for my manufacturing organisation to achieve a leaner environment? To help address this question, in this paper we present a set of diagrammatic tools to guide researchers and practitioners through the process of identifying lean opportunity in RFID. The set of tools make use of the 7 Toyota manufacturing wastes identified by (Ohno 1988) and show the user how RFID may reduce waste by increasing data quality.

The rest of this paper is structured as follows:

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3 *Section 2* presents key literature in identifying value in RFID, *Section 3* analyses how RFID can help reduce the
4 seven wastes of manufacturing used in the Toyota Production System, and presents the opportunity analysis
5 guide, *Section 4* presents case examples to put the guide into context and enable a better understanding of the
6 approach, and *Section 5* concludes the paper.
7

8 **2. Related Work**

9
10 In this section we review key literature on the use of RFID, and reported implementations in
11 manufacturing. We also examine studies on the estimation of value that RFID brings.

12 (Redman 1998) mentions four types of data quality issues in companies: issues of data views, such as
13 granularity and relevancy, issues of data values such as accuracy, timeliness and completeness, issues with the
14 presentation of data, and finally privacy and security related issues. RFID, as an enabler of automated data
15 collection, has the ability to address issues related to data views, in the form of increasing the granularity and
16 respecting data dependencies, and issues related to data values, in the form of increasing accuracy and
17 completeness real time.

18 In the field of manufacturing RFID has found a wide range of uses through improvements in data
19 quality. A number of these include inventory management (Mills-Harris et al 2005, Cachon and Fisher 2000),
20 manufacturing asset tracking and maintenance (Lampe et al., 2006, Strassner and Chang 2003), process
21 tracking (Huang G.Q. et al., 2007), and dynamic improvements in production planning (Brewer and Sloan
22 1999, Li et al 2006). Recently, (Hozak and Hill 2008) showed how ideal frequencies of production
23 rescheduling may be concluded through the use of timely information provided by RFID technology. Other
24 innovative applications include automated control (Keskilammi et al 2003, Thiesse et al 2006), and intelligent
25 products (McFarlane et al 2003, Zhekun et al 2004, Kärkkäinen 2003).

26 (Gunasekaran and Ngai 2007) predicted that new technological platforms, partly based on RFID, will
27 help manufacturing companies in knowledge diffusion and transfer in the 21st century, in various areas from
28 planning production and logistics, to the gathering of customer service requirements once products are in use. To
29 this, (Jun et al 2007) added that the end of life recovery of products and their integration into the manufacturing
30 phase can also be aided by technological frameworks including RFID.
31

32 On the other hand, case studies offering real life manufacturing examples of RFID use are limited in
33 number. Some articles include: (Strohbach et al. 2004), who studied a system for handling and storage of
34 chemicals in a chemical plant, (Thiesse and Fleisch 2008), who report on the design and implementation of a
35 real-time identification and localisation system in a wafer fabrication facility to reduce stock and improve
36 efficiency, (Johnson 2002) who reported on the RFID implementation for assembly process control in the Ford
37 Company plant in Mexico, (Günther et al. 2008) who reported on six case studies on the use of RFID within
38 manufacturing process tracking. More recently, (Patti and Narsing 2008) acknowledge that lean manufacturing
39 is compatible with RFID through industrial examples at lean firms, including assembly part location tracking
40 and electronic Kanbans.

41 The abundance of academic literature in potential manufacturing applications is supported by very few
42 real life case studies. This observation points to a lack of industrial trust on the value RFID may bring in
43 manufacturing operations and as a result few of the conceptual ideas are exercised in real life. To achieve
44 industrial trust, either there must be a rich source of case studies, or clear, justified tools and techniques to
45 enable the estimation of value of RFID in manufacturing. When it comes to predicting how and where RFID can
46 bring value, (Dutta et al 2007) highlighted three camps of academic research: empirical research that conducts
47 statistical analysis in finding out how RFID helped companies, (such as that of Hardgrave 2005), simulation
48 based research that uses Monte Carlo models to estimate the impact of RFID (such as that of Lee et al 2004,
49 Fleisch and Tellkamp 2005, Lu and Cheng 2005, Brintrup et al 2008), and the development of analytical models
50 in examining RFID's value for an organisation, (for example Lee and Ozer 2003, Gaukler et al 2004, Karaer and
51 Lee 2007). Many papers in the last camp have their focus on the supply chain, and do not consider
52 manufacturing applications within the four walls of a factory. (Lee and Ozer 2003) mention a "credibility gap"
53 in RFID value identification as there exist numerous reports and whitepapers that claim benefits based on
54 qualitative judgement, without explaining how these benefits can actually be reached. As a response, (Lee and
55 Ozer 2003) present an analytical model of how increased visibility in the supply chain with RFID can result in
56 reduced labour cost, improved supply chain coordination, reduced inventory, and increased product availability.
57 (Gaukler et al 2004) present an analytic model of the shared costs and benefits of implementing item-level RFID
58 in a supply chain of many partners. (Karaer and Lee 2007) quantify savings resulting from increased reverse
59 channel visibility with RFID, in the case of a manufacturer's decision making process on returned items.

60 Manufacturing managers tend to view case studies as preliminary modes of investigation, unless there
exist abundant studies on the application they consider. Existing statistical analysis mostly points to supply chain
applications of RFID. Monte Carlo based analysis or analytical models are well grounded, but the former require

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3 large amounts of time and data, and the latter is theoretical, not to mention existing models are once again
4 supply chain oriented. We propose that an additional step is necessary to persuade manufacturers to invest time
5 in pursuing such analytical modes of analysis, in which manufacturing managers can quickly identify potential
6 areas of analysis, and relate RFID with manufacturing benefits.

7 We found the use of lean manufacturing principles in showing and identifying value in RFID is in line
8 with our vision of a preliminary step. In the lean manufacturing context, “manufacturing waste” is any raw,
9 work-in-process or finished inventory, labour or processing time, energy, space and resources, in excess of the
10 minimum that is required to efficiently run production. Obviously scraps and defected products are also
11 classified as manufacturing waste (Shingo 1989). Numerous papers present practices to identify and reduce
12 manufacturing waste, in the form of case studies, and methodologies. The development of actions taken to
13 eliminate waste gave rise to the term “lean production”. Among many other authors, (Womack and Jones 1996)
14 and more recently (Fullerton and McWatters 2000) and (Fullerton et al 2003) supported that lean manufacturing
15 practices do result in increased profitability, through surveys of numerous academic case study papers. (Bonavia
16 and Marin 2006) cite many reviews of how lean manufacturing practices impact on performance. Therefore we
17 hypothesise that the use of the lean manufacturing template could serve the purpose of convincing manufacturers
18 in identifying value in RFID.

19 With this aim, we provide a guide for clearly identifying opportunities for using RFID to bring value
20 through leaner manufacturing. Although lean activities consist also of procurement, we are concerned in this
21 paper, of only lean processes. The set of diagrammatic tools, described in the following section, are designed to
22 help companies understand data quality in their processes, how data quality issues translate into manufacturing
23 waste, and how it can be improved using RFID.

24 25 26 3. The RFID opportunities toolset

27 We highlighted the need for a structured framework to identify value-added by RFID deployment.
28 While benefits of RFID deployments differ with the specifics of the manufacturing process we can address the
29 need by contemplating the reduction of the seven wastes of manufacturing systems through RFID technology.
30 After a brief analysis of waste in manufacturing and its correlation with low data quality, this section presents
31 tools to identify and generate lean value with RFID.

32
33 (Ohno 1988) has identified the following seven wastes in manufacturing systems:

- 34 1. Overproduction: discourages a smooth flow and leads to excessive lead and storage times.
- 35 2. Waiting: occurs when time is being used ineffectively.
- 36 3. Transport: a non-value adding operation which involves goods being moved around.
- 37 4. Inappropriate processing: occurs when systems or procedures more complex than necessary are used,
38 leading to excessive transport and poor quality.
- 39 5. Unnecessary inventory: unused capital, leading to storage costs, or possible quality deterioration of goods if
40 the time of storage is critical to its health.
- 41 6. Unnecessary motion: the ergonomics of production when employees need to move in unnatural positions
42 repetitively, possibly leading to tired employees and compromises on quality.
- 43 7. Costs of defects: wastage of produced material that could potentially bring revenue.

44
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46 Let us consider an occasion when a barcode scan during a goods issue operation to a physically
47 transforming process step is not carried out at step B exit (Figure 1 (a)). The information system shows a certain
48 amount of material under a process step C. This scenario has various implications in the above waste categories
49 where RFID technology offers a number of direct and indirect benefits.

- 50 • In the case that the machines allocated to the subsequent process need reconfiguration the information
51 system may ask for the changes to be made in advance. Looking at the alerts from the information system,
52 Process C awaits the arrival of the next batch to go from A to B to start reconfiguration, missing out on the
53 valuable time that could have been used to prepare machinery for the next batch, as it assumes there is time
54 remaining. This mismatch leads to time wastage in machine setup, i.e. *waiting waste*. Some information
55 systems will lock and not allow further data to be processed until the operator corrects data manually. If
56 operators ignore warnings and continue processing, we will have further loss of traceability and valuable
57 reconfiguration time.

58 <<INSERT FIGURE 1>>

- The batch may be transported back to Process B to be re-processed since we have lost traceability on whether the process has actually been carried out, leading to possibly *inappropriate processing*, *transportation waste* and *defects*. Even if the system self-corrects and claims that Process B has occurred, there will still be a traceability loss since we do not know whether the item has actually passed through process B or not. For some companies such as food manufacturers, this means the whole batch needs to be scrapped due to non-compliance with traceability mandates. Pin pointing exact process steps that results in defected products is important to resolve issues quickly, and might not be possible when traceability is lost.
- The shift manager may decide to scrap the batch if traceability for that process was critical; for instance in the case of a batch quality testing process, leading to *defects*.

Let us consider another scenario (Figure 1 (b)) where an employee scans the wrong barcode and associates another batch type with the subsequent process. Since the Process A for this batch is not completed the batch might be sent for re-processing leading to wastage in *transport*, *waiting*, and possible *defects*.

- With the scanning of the wrong barcode, two different batches from one are created, leading to an inaccurate picture of *inventory* and *overproduction* of batches for which the information system displays to have incorrect stock level.
- According to the information system the set of machine resources carrying out Process A seem to be occupied with the batch assigned to it, while in reality it is not. This causes other batches to wait in the queue until the error is found out and corrected.
- If the initial batch record is associated with a quality restriction and the newly aggregated batch is not, the scan error may lead to the production of substandard quality goods, leading to severe *defects* and hence, wastage. In both of the scenarios if the error is noticed and correction is attempted, time spent in managing information is increased, leading to time wastage through *waiting*.

A study performed by one of our case study companies showed that missed or wrong barcode scans occur approximately 10% of the time, which led the company to seek alternative ways of data collection. Although the above scenarios are typical of work in progress management (WIP), the above mistakes can easily be replicated if WIP products are taken as an analogy to assembly operations in automated production control. In inventory management, reliance on barcode scanning and human factors may result in *overproduction* wastage, as wrong scans are performed for goods in and out of the warehouse. The search for the correct products in storage facilities lead to wastage through *transport* and *waiting*, and the deterioration of overproduced or untraceable products in the warehouse lead to *defect wastage*.

Finally, in application scenarios, employees are relieved from handheld barcode scanning or manual data recording operations if appropriate reader and antenna arrangements are used, leading to the elimination of *unnecessary motion wastage* as well as human errors in the scanning processes.

Observing how poor data collection, dependencies and visibility result in waste, we now propose four visualisation tools to allow practitioners to assess their manufacturing processes from a wastage reduction point of view and think about where RFID can help. The tools sit under three categories: data collection (automatic collection of process data), data dependencies (timely conformance of data dependencies for processes), and visibility (increasing process visibility) each highlighting different wastes and helping the manufacturer identify how RFID may improve these. Understanding current process and building lean value on them through RFID corresponds to the point made by Saygin: “business cases need to be built on defined rules, and without reaching a lean perspective on operations and workflow in an organisation, RFID cannot bring visibility out of a chaotic environment” (Saygin C. and Sarangapani J., 2006), suggesting the need for a complete understanding of processes affected from RFID implementation.

3.1 Data collection

<<INSERT FIGURE 2>>

Two types of manufacturing waste are created in situations where data collection is performed through barcode scanning or manual data entry: *unnecessary motion* performed by operators and *transport waste*, created by bringing items to scan locations. To identify where these types of waste are created and whether RFID can address them, two tools, offering different angles of view are suggested: Process Diagram (PD), and Use-Case Diagram (UCD).

Process Diagram (Figure 2) is designed to identify where data collection operations lie along the manufacturing plant. The resulting map depicts data entry and pull locations and the method of data collection or entry (such as manual barcode scans, paper or computer entries), projected among a representation of the manufacturing locations. Current data pull and push points are numbered. Where there is more than one of the same type of data point (such as one hundred moulding machines, each consisting of the same data step) only

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3 one data point is depicted and the numbers of different units are given next to it. In addition to providing
4 information on data collection operations, the physical representation also illustrates the complexity of
5 production routes from a geographical point of view. The diagram acts as an intuitive start point in thinking
6 where RFID can be potentially replace manual data collection and the extent of data operations. It provides a
7 snapshot of data projected upon operations, and can bring to light which operations are not associated with data
8 and therefore not traceable.

9 The Use Case Diagram is based on the Unified Modelling Language (UML), a generic modelling
10 language commonly used in software engineering. The diagram is used to model functionality of a system from
11 an actor-use case point of view. The actors of the system present use cases i.e. functionality, and the lines
12 represent dependencies between these elements. Detailing the manufacturing system in this manner enables the
13 identification of the possible levels of automation during data collection and which actors are affected by the
14 automation. For instance operator barcode scans can be automated, which would impact the use cases of
15 information system actors.

16 The results of the process diagram and the UCD give a complementary view of how data collection is
17 performed throughout the manufacturing process. While the process diagram shows physical data collection
18 points and complexity of production routes, the UCD shows the particular actor(s) collecting the data. The next
19 step is to find those actors that may cause errors and inaccuracies and analyse if an RFID based automated data
20 collection process is capable of replacing the actor(s).

21 22 23 **3.2 Data dependency**

24 <<INSERT FIGURE 3>>

25
26
27 Data capture automation through RFID makes sure that data dependencies of manufacturing processes
28 are respected throughout the process flow. Four types of manufacturing waste are created due to failures in
29 timely conformance to data dependencies: *waiting*, if incorrect data results in delays when error is noticed and
30 correction is attempted, *defects*, if incorrect data results in wrongly processed products, *overproduction*, if
31 incorrect data results in producing more WIP products than necessary, *unnecessary inventory*, if incorrect data
32 results in producing more finished products than necessary.

33 A Data Dependency Diagram (DataDep) is suggested to identify where the four wastes are created and
34 whether RFID can be used to address them. The DataDep shows data dependencies and where manual or
35 barcode based data collection occurs and therefore the process may be vulnerable to error. Figure 3 shows a
36 DataDep, here each product value adding step is depicted as a product transformation step. Each transformation
37 step is dependant on a number of data inputs, shown as input boxes to the step. Data gathering can be carried out
38 in a variety of manners, including manual data entry, manual records on paper, or barcode scans. In addition,
39 data itself can be transformed in terms of format, for example from a paper based record to an electronic record
40 on an Electronic Resource Planning (ERP) system. The frequency of data collection is associated with the input.

41 Resulting from this activity is a map of data dependencies existing across the process flow. The
42 DataDep is used to understand (1) what would cause a data error for each process data input creating waiting,
43 defect, overproduction or unnecessary inventory wastes, and (2) if and how data collection frequency could be
44 increased though RFID.

45 46 **3.3 Visibility**

47 <<INSERT FIGURE 4>>

48
49 Visibility is significant contributor to giving effective stock order or goods issue decisions throughout
50 the manufacturing plant. Yet current methods for performing an inventory count or for tracking asset movement
51 do not provide real-time visibility leading to decisions based on outdated, inaccurate information (Lu et al.
52 2006). Lack of visibility on work-in-progress (WIP) and finished inventory is the root cause of the Bullwhip
53 Effect in the forecast-driven supply chain, where safety stocks for each supply chain participant are increased
54 due greater observed variation.

55 Two types of manufacturing waste are created in situations where visibility of operations is
56 compromised: *overproduction*, when low visibility leads to the belief that the WIP stock of levels of a given
57 item is lower than the actual stock, and *unnecessary inventory*, when low visibility leads to the belief that the
58 finished stock level of a given item is lower than is the actual stock. RFID can increase data visibility throughout
59 manufacturing processes at two possible levels, batch level and item level; and it can help track stock at
60 individual manufacturing processes. The combination of the location and item or batch level identification of
products gives the decision makers a more accurate and real-time sense of on-going operations in terms of the
time taken to complete a process by an associated batch or item.

To identify where visibility can be increased and its effects on inventory levels, a Data Visibility Diagram (DataVis) is suggested (Figure 4). There are four simple steps involved in each process step of this approach, as listed below.

1. Outline
 - the level of visibility at each process step (i.e. no, batch or item level information)
 - Recipients of process visibility information (i.e. whom or what the process is visible to)
 - Information that is made visible (e.g. time taken to complete a process, location of the process, and the degree success for a process)
2. Discuss the impact of the level of visibility on the subsequent process step in terms of buffer or work-in-progress stock
3. Modify the outlined visibility parameters
4. Discuss whether the modified parameters increase the level of visibility and create a positive impact on stock decision making

Table 1 shows a summary of the tools and their use in identifying where RFID can be used to reduce relevant manufacturing waste. The opportunity analysis should consist of identifying waste estimates in the organisation through a series of interviews with managers, such that the results of the initial discussion can provide a basis for validating the mapping process once it is completed. The mapping process can commence with the tool set offering the estimated wastage. Descriptions of the wastes can be made to managers by giving them relevant examples without introducing bias. Once mapping is complete a set of requirements will emerge for the practitioner which can be used to devise a technical feasibility analysis in the next stage.

3.4 Value driver identification

<<INSERT FIGURE 5>>

After identification of the wastes that RFID technology can address, our next step is the identification of value drivers associated with the elimination of the waste. Value drivers which can be addressed under RFID are:

- *Inventory related value drivers*: Inventory is held in order to manage supply chain fluctuations, and to ease the effect of imperfections in the manufacturing process. Inventory is immobilised and hence regarded as non-working capital. By providing better visibility of goods being manufactured or stored, RFID can help optimise inventory levels by minimising safety stock, and tracking discarded inventory.
- *Time related value drivers*: By improving visibility across manufacturing processes, lead times are reduced as unnecessary delays in searching for goods are eliminated, ultimately leading deliveries made within time constraints imposed by contractual obligations.
- *Decision support value drivers*: These include improvements leading to better financial decision making in areas such as raw material demands, supply forecasting, and process reengineering.
- *Handling efficiency value drivers*: Impact of RFID on labour is obtained by reducing the amount of man hours required for the same amount of work to be completed, such as work done in information collection and management, location of stock. Minimising wastage of goods due to wrong scans and minimising wasted inventory due to better implementation of various stock rotation systems are also accounted under these value drivers.
- *Quality improvement value drivers*: These include adherence to quality mandates by ensuring traceability of goods through various manufacturing processes while assuring removal of blocked or unsuitable goods out of process flow. Other impacted areas are in container or equipment management through tracking of their maintenance history to ensure reliable operation which otherwise could be potentially damaging to the quality of the manufactured goods.

Figure 5 shows the relationship between the value drivers discussed above and the seven wastes where accomplishing each value driver lead to benefit and a reduction in waste. Quantifiable benefits result from clear cut links from implementation to simple functions of costing. For example replacement of a manual barcode scan with an automated scan using RFID technology results in reduction of labour costs.

Unquantifiable benefits are those that cannot be associated with a simple function of cost. Taking brand integrity damage as an example, let us assume that a company would like to raise an alarm when a sample from a given batch of goods fails to conform to a default quality standard and the batch is about to be used in later stages of production. The information about the sample's quality status resides in a central Information System. To link this information to the batch of goods the operator needs to scan the batch identification and inquire about its quality. In the event of an operator failing to perform the scanning operation there is a risk of the batch of goods proceeding further in the production process and, perhaps, eventually entering the supply chain. Using RFID to automate the scan operations will ensure that faulty goods are detected and removed. An attempt at the

quantification of this benefit would need probability estimations on operator failure and batch quality failure, cost of recalling goods from further along the manufacturing processes or the supply chain or from consumers who have purchased the faulty goods. As a result of the rising complexity in calculations companies often classify such benefits as “soft benefits”. Other RFID related benefits that may fit into the “soft” category are reducing lost sales, improved employee productivity by the removal of scanning responsibility, and better customer satisfaction due to improved traceability.

4. Case examples

For the reader to gain a better understanding of the approach, this section presents three brief case examples highlighting the use of each component of the toolset. The companies used are a food and confectionary manufacturer and a fragrance manufacturer. Both fast moving consumer goods manufacturers follow centrally controlled push-based manufacturing, and were interested in gaining quick predictions of where RFID could bring value in their processes by eliminating waste. They questioned RFID to be a vehicle to leaner operations, although they did not necessarily follow lean tools or principles. They both deployed barcode systems to trace their current production processes and looked to RFID as an enabler of automated data collection to replace the barcode systems. Their common characteristics and interest in quick predictions made them highly appropriate as choice of case examples. Semi-structured interviews performed with the management team, who were primarily responsible for analysing RFID’s potential. During the interview, we recorded interviewees’ answers. Each interview took around 1 hour.

During the interview subjects used our toolset to analyse existing production processes and discussed where RFID can bring value. The research team helped the subjects in using the toolset. When data was not readily available, it was obtained at a later stage from archival data and follow up interviews were conducted. This process enabled us to use Yin’s principles of rigorous data collection (Yin 1994): multiple sources of data, and recording of case study data. The process took no more than three interview sessions with each company. We summarise our findings below.

Case 1: Confectionary production

<<INSERT FIGURE 6>>

1. The company employing the data collection component is a multi-national confectionery and food producer following a centrally controlled batch manufacturing philosophy. The mass of low skilled temporary operators in the food manufacturing sector resulted in an especially higher probability for loss of traceability due to barcode scanning errors. Therefore the company primarily looked into deploying RFID technology to replace the existing barcode scanning operations with an automatic data capture technology and conform to legislative traceability mandates required for health and safety. Using the guide presented in this paper a variety of other requirements emerged, pointing to areas of value drivers and waste reduction. When discussed with the management team, the following action points were summoned as a result of analysis with PD and UCD (Figure 6 (a) and (b)):
 - Complex production routes result in high numbers of work-in-progress buffers and high probability of errors in correctly storing and locating items. High numbers of barcode scanning operations coupled with complexity of routes and variations in process barcodes result in *unnecessary motion* which could be automated with RFID.
 - The high number of wrapping (a specific part of the production process) locations dictates a more cost effective solution. Installing RFID on forklift trucks and tagging the wrapping point locations can be an alternative to installing RFID scanners on each process location.
 - Washing of containers that carry batches of products, and the tipping process are not fully tracked, giving rise to possible wastage in *defects, inappropriate processing, overproduction, waiting* and *unnecessary inventory wastage*. Debris collected in the containers may lead to defected products unless washed every set number of uses. The usage history of containers is manually recorded, and the recording process might often be overlooked. At times the container over-usage is detected late in the process, which results in unnecessary waiting whilst other containers are being sought. An automated tracking system using RFID will count the number of times a container is used and help generate a wash alarm. The tipping process is not tracked, and may therefore lead to inaccurate pictures of inventory, and overproduction. Automated tracking at the tipping process is appropriate as operators tend to overlook scan operations during frequently performed, complex processes. A read point is to be installed at this process and communicate batches that undergo tipping to the ERP system. Value drivers from improving these two points will include improvements in *quality, inventory* and *time*.
 - The high number of work-in-progress containers and possible locations they can be in makes inventory counts error-prone giving rise to *overproduction*, and *unnecessary inventory*. An RFID based inventory management system can be beneficial. Here inventory counts will be automated through the installation of

inbound and outbound read points at each process buffer. Value drivers from improving this process include improvements in *inventory* and *decision support*.

- The UCD on the other hand showed the existence of many non-automated data pulling operations. Requirements raised from this step of the analysis were the automation of barcode scanning and manual recording processes to result in a leaner manufacturing environment.
- Before an item is tipped on the wrapping line, its quality status needs to be checked by the operator using a barcode scanner and information displayer. Then several information system layers (Middleware, Manufacturing Resource Tracking (MRT), Business Integration Framework (BIF), and Enterprise Resource Planning (ERP)) are parsed through to arrive at the quality status information which is sent to the display.
- Requirements raised from this exercise were the automation of barcode scan and manual recording processes to result in a leaner manufacturing environment. The automated RFID would take on the role of the operator to query quality status when a bulk container is brought to the wrapping location. The barcode actor is eliminated, and the operator takes on the new role of “terminate process” if the display shows wrong quality status.

Case 2: Coffee aroma production

<<INSERT FIGURE 7>>

2. Figure 7 shows the DataDep of an example process of the same food manufacturer. The process involves the capture of pulverised beverage aroma from a coffee roasting process, its cold storage and reuse. Process steps were found to be highly data dependant and reliant on the manual pull/push of information by the process operators, causing severe delays and errors. Some process steps, although dependant on quality inspection data, do not come to a halt if this data is not present, which ultimately leads to quality errors at later stages of production with increasing cost of recalls. For instance, before goods are actually used or reworked, three data are necessary: the call for an aroma tub, the location of the tub (in line with first-in-first-out), and the tub’s quality inspection outcome. None of these data are automatically collected. The reliance on the operator, makes the process error-prone in terms of data completeness. RFID based first-in-first-out inventory management, and automation of the alarm raising when items fall below a predefined quality status would make sure data dependency is respected in this process. Using the above analysis, the manufacturing wastes were identified as: overproduction & unnecessary inventory due to low visibility of work-in-progress and finished product inventory; unnecessary motion due to high numbers of repetitive barcode scan operations; and defects due to scanning errors, leading to association of wrong process steps, and wrong quality material being used. Wastage was found in the areas of *inventory*, *overproduction*, *unnecessary motion* and *defects*, pointing to value drivers in *inventory*, *handling efficiency*, *quality improvement* and *decision support*. The quantifiable benefits included a reduction in man hours, scrapped material due to loss of traceability, and reduction in safety stock. The company required a total cost of ownership for the RFID system installation, revealing a projected positive net present value after two years of installation.

Case 3: Fragrance production

<<INSERT FIGURE 8>>

3. We consider the case of a fragrance manufacturing process from a cosmetics producer. The use of data visibility diagrams showed that parts of the manufacturing process were not captured by the existing bar code scanning methods (Figure 8). The analysis reveals that some parts of the process were not captured, giving raise to inaccurate WIP inventory levels. Containers that carry work-in-progress materials were at times not visible as they always moved or their barcodes were damaged, and could not be counted, leading once more to inaccurate *inventory* information. When raw material is received, items were booked into the information system only after certain quality tests are done. This could result in delays finding raw material and *waiting* in the production line for items from suppliers that were already in stock, and at times, re-ordering of items. The final stages of the process, packaging and palleting, collected batch level information which was only visible to the operator until dispatch. The line fill process was not captured and items could be lost in the storage location associated with finished items. It was found that some inventory related data that was collected during production was not visible at the ERP level, which resulted in an inaccurate picture of inventory, and consequently wrong orders placed by procurement officers. The requirement emerged that synchronised, timely and accurate information is visible at all levels of information hierarchy. Furthermore, a transition from batch level information to item level information was required in the dispatching process to provide accurate record of dispatched items. This exercise resulted in *time* and *inventory* related value drivers.

In all case examples the tools proposed helped practitioners pinpoint lean opportunity and value drivers in using RFID. As a next step, practitioners should evaluate the emerging requirements from the use of these tools in terms of feasibility and benefits over cost. Feasibility analysis in RFID implementations need to cover not only technical compatibility of the object and physical environment RFID is to be applied, but also the extent of operational change required when implementing RFID.

5. Conclusion

There are few value identification tools for RFID at the disposal of manufacturers: promotional vendor estimates and whitepapers, empirical research and case studies on value brought by implementation, analytical operations management models and simulation based analysis. The first is viewed as biased by managers. The second and third are few and mostly supply chain oriented. The fourth requires time and effort. To convince managers to use analytical models or simulation, a preliminary step is necessary in showing where RFID can bring value. Building on this observation, we identified how RFID can serve as a vehicle to reduce the seven wastes of manufacturing and outlined a new, value-driven opportunity analysis toolset to achieve leaner manufacturing. The toolset identifies where RFID can bring value through automated data collection, conformance to data dependencies and improvements in visibility.

Following the opportunity analysis practitioners should look into the feasibility of addressing the opportunities identified from a technical, operational, organisational, and human factors point of view. Requirements resulting from the opportunity and feasibility analysis could be put into the business case for formulating operational and capital expenditures, using analytical models given in literature or simulation based analysis. It is also necessary to note that RFID technology itself may not always provide 100% read rates due to various factors including RF interference, material that the tag is attached to, and harsh environments that impact the read rate. Comparisons with barcode or manual data recording systems should take these considerations into account.

The toolset is tested on case examples from two manufacturing companies. The results show that the framework addresses a gap in literature by providing a comprehensive but not exhaustive list of wastes and also provide a self-help guide to companies to “discover” value in RFID technology. The current toolset biases itself to data quality improvements on existing processes and thus does not look into innovative applications of RFID, such as intelligent products or distributed production. It needs also to be further validated in companies using pull-based production. Our next step in this work is to examine the use of these tools in pull-based production and to perform a simulation study to link increases in data quality with waste reduction, which we hope will provide practitioners with a quantitative and user friendly method to find lean potential in RFID.

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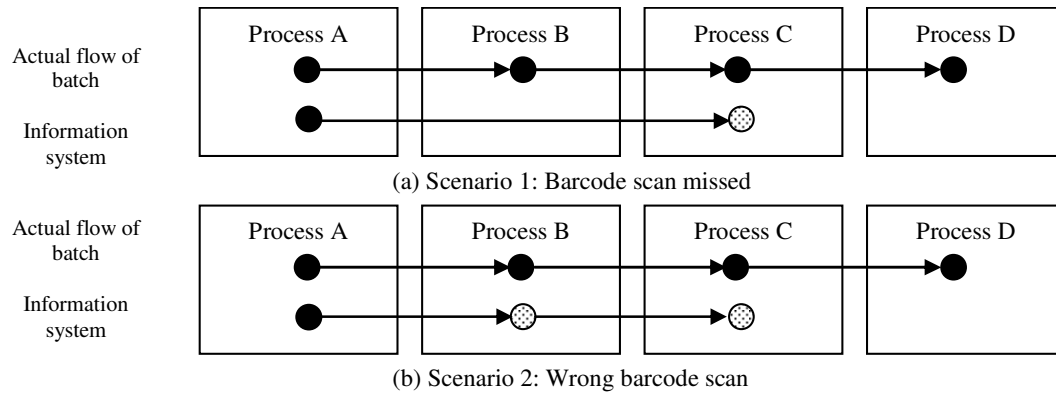


Figure 1 Information discrepancy scenarios

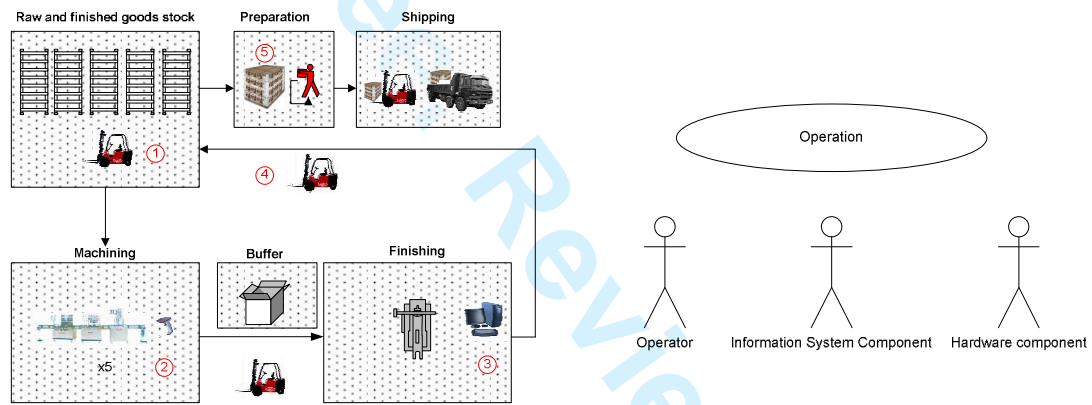


Figure 2 Process Diagram and UML Use Case Diagram

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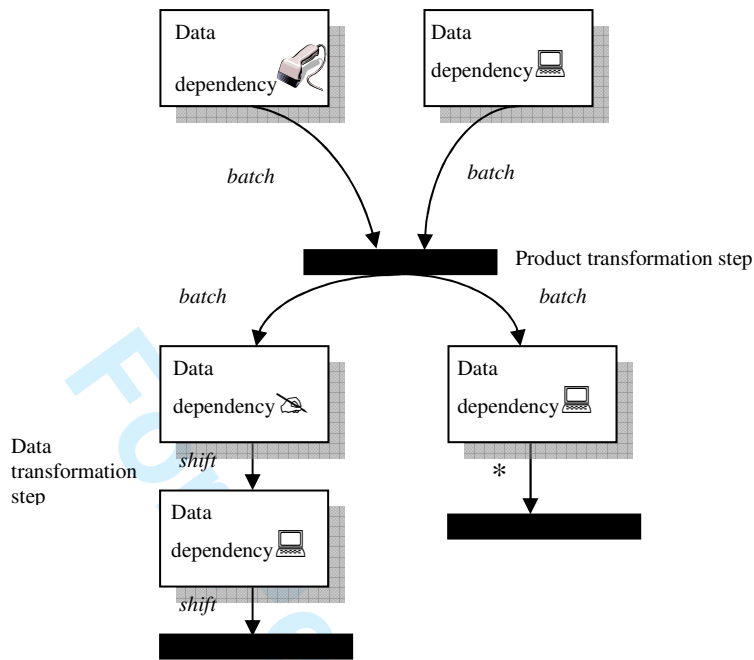


Figure 3 Data Dependency Diagram

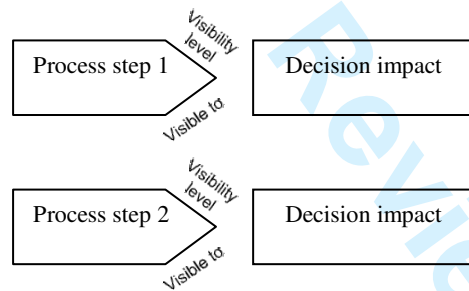


Figure 4 Data Visibility Diagram

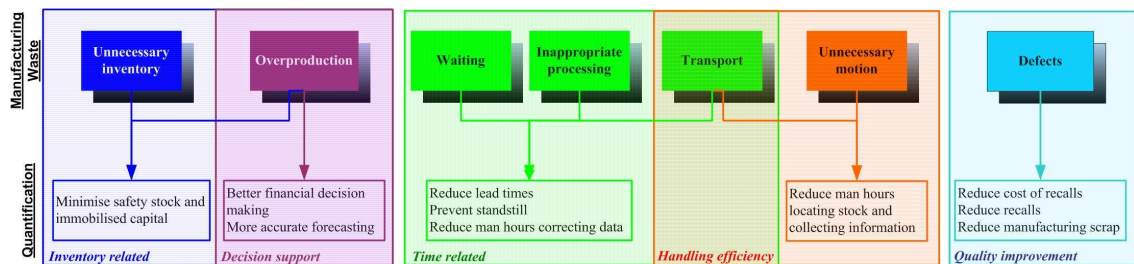


Figure 5 From Manufacturing Waste to Value Drivers

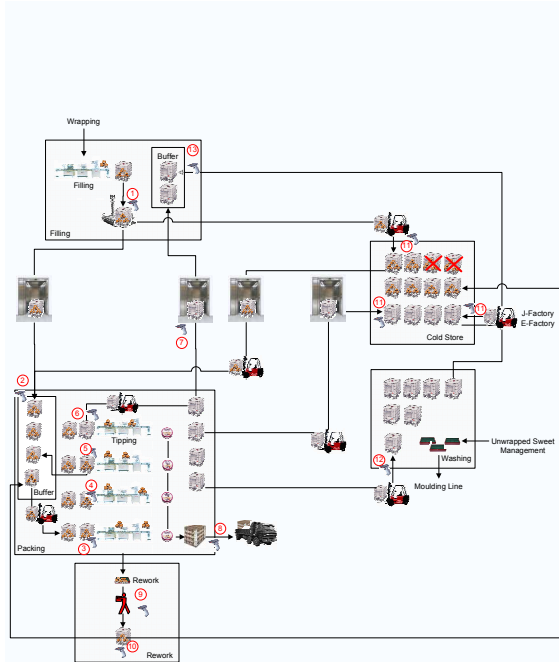


Figure 6 (a) Case 1: Process Diagram

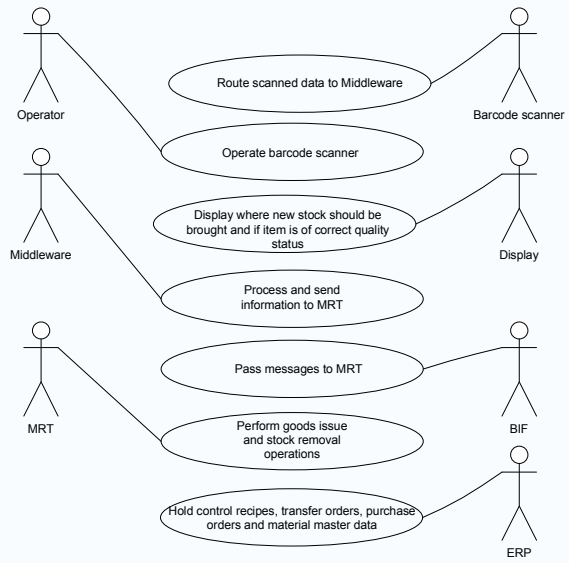


Figure 6 (b) Case 1: Use Case Diagram

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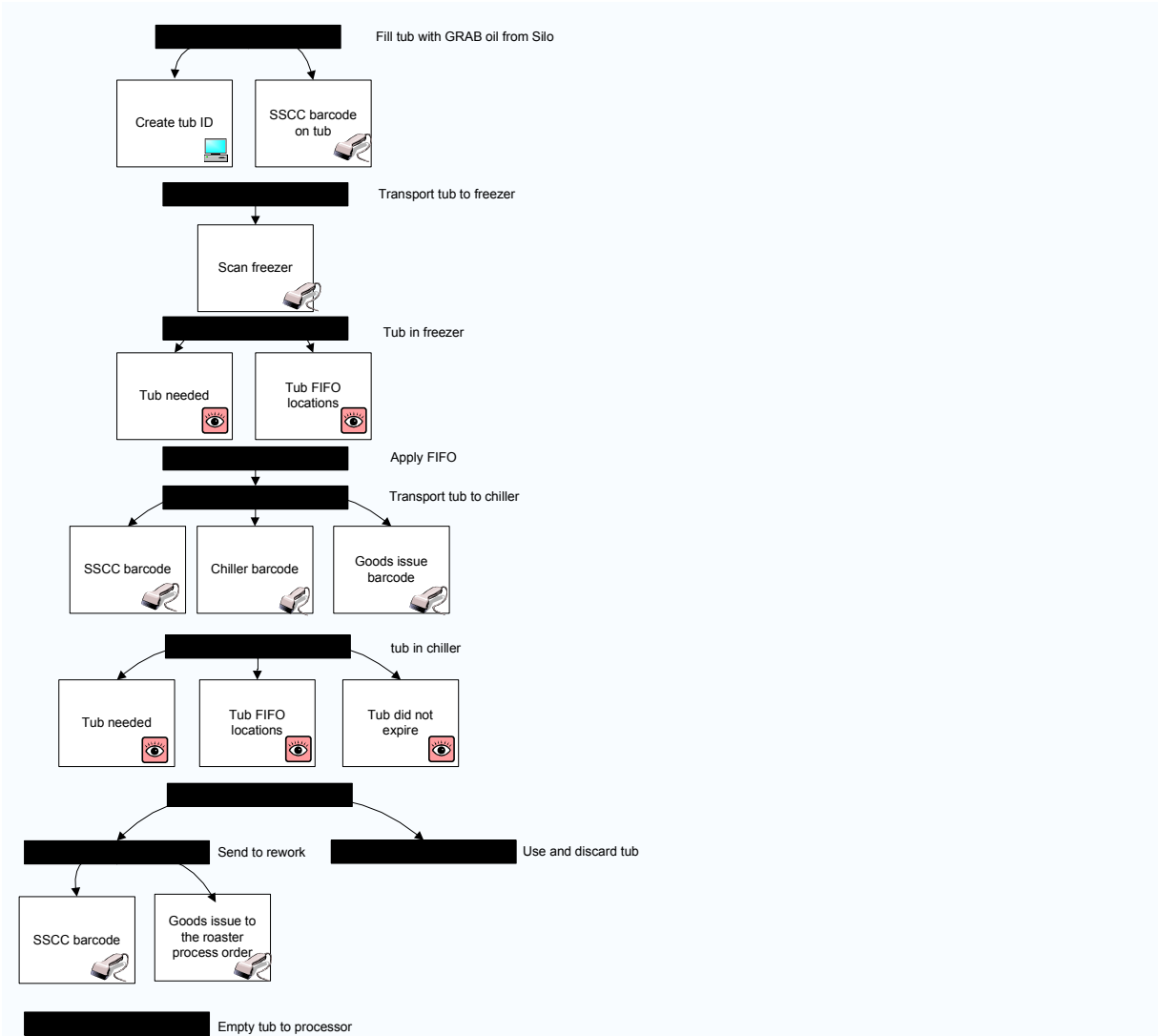


Figure 7 Case 2: Data Dependency Diagram

Manuscript Only

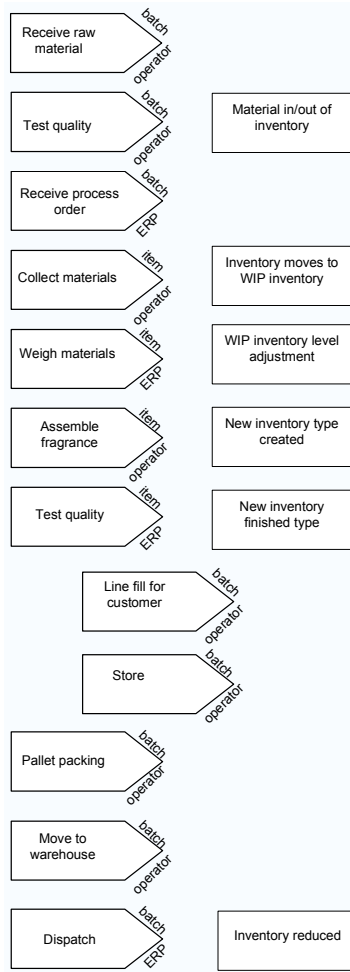


Figure 8 Case 3: Data Visibility Diagram

New Only

Table 1 Toolset for RFID opportunity analysis.

Tool	Waste identified	Origin of tool	Description
Process Diagram	Unnecessary motion Transport	New	Identifies manual data collection points, geographical distribution of data locations leading to unnecessary movement of operators and products
Use-Case Diagram		Object management group	Depicts the use cases that the current system is capable of performing and actors taking part in system functionality. Suitable for differentiating parts of the process carried out by error prone actors from operational parameters modified by the information system.
Data Dependency Diagram	Waiting Defects Overproduction Unnecessary inventory	New	Identifies decision points in processes to assess the importance of data capture and highlights the processes affected from errors Identifies the level of concurrency involved in operations and whether process performance is improved by automating conformance to data dependencies.
Data Visibility Diagram	Overproduction Unnecessary inventory	New	Identifies the manner in which the level of visibility and parameters affect batch sizes, and work in progress and finished inventory.