Remanufacturing with RFID Item-Level Information

Wei Zhou[1,3] and Selwyn Piramuthu[2,3]

[1] Information Systems and Technologies, ESCP Europe, 75543 Paris cedex 11, France
[2] Information Systems and Operations Management, University of Florida, FL 32611, USA
[3] RFID European Lab, Paris, France
{wzhou@escpeurope.eu,selwyn@ufl.edu}

Abstract. RFID technology has been widely utilized throughout supply chains across a wide spectrum of industries. However, its potential in recycling/remanufacturing has not received much attention in information systems literature. We consider RFID tags and their applications from a recycling/remanufacturing perspective and propose a novel framework to assist such process based on item-level information visibility and instantaneous tracking/tracing ability enabled by RFID tags.

Keywords: RFID, remanufacturing, reverse logistics, item-level information, closed-loop manufacturing.

1 Introduction

In recent years, Product Remanufacturing Management (PRM) and closed-loop manufacturing have gained increased attention from academic researchers and practitioners alike. The process of remanufacturing include the collection of defective (due to manufacturing) and end-of-life goods as well as manufacturing byproducts and re-engineering of products back to new or as-new or refurbished condition. Although remanufacturing is not new, it is still largely undervalued with respect to its economic, environmental and social benefits as well as from a strategic business perspective.

Due to its inherent properties and the need to integrate the remanufacturing processes with the regular manufacturing plan, product remanufacturing management has been faced by challenges that arise mostly as a result of uncertainty from a supply chain perspective. For instance, uncertainty from the market, inventory, processing time and materials recovered has a direct impact on the manufacturing plan. As a result, the complex tasks in a remanufacturing process normally are significantly different from those in a traditional manufacturing setup. Rather than tackle a part of the problem, we find it more beneficial to optimize the remanufacturing process as a whole, which makes RFID technology an ideal candidate for this purpose.

Being able to reveal item-level product information in a way that is fully automatic and instantaneous, radio frequency identification (RFID) technology not only provides a vitally important tool for supply chain management but also makes it a natural fit to optimize the product remanufacturing process. RFID is a tracking system that

R. Sharman, T.S. Raghu, and H.R. Rao (Eds.): WEB 2009, LNBIP 52, pp. 96–104, 2010.

uses tags (silicon chips implanted in a product or its packaging) to transmit information to a wireless receiver. The tag contains relevant product information at an item-level (Raza, Bradshaw, and Hague 1999; Shepard 2005; Zhou 2009). Unlike bar code that provides categorical-level information, RFID technology facilitates distinguishing individual products by assigning a unique electronic product code (EPC) to each of them. Unlike bar codes, which need to be seen to be scanned, RFID tags do not require direct line-of-sight for data transmission, making it possible to simultaneously read several tags as a batch.

Motivated by RFID's unprecedented characteristics for auto identification, we propose a framework to utilize RFID item-level information for product remanufacturing based on an adaptive knowledge-based system. We consider product remanufacturing process from a heuristic perspective with the goal of (1) reducing both environmental and economical waste, (2) improving manufacturing quality to decrease the rate of defects, (3) improving the efficiency of remanufacturing process, (4) facilitating product design and (5) enhancing Customer Relationship Management (CRM).

Because of the complexity of both tasks and data in the remanufacturing process, an adaptive learning system is chosen to assist the process. Given the nature of remanufacturing, it is essential for the system to be adaptive to facilitate the need to be flexible in dealing with disparate scenarios that are endemic to this domain. A knowledge-based adaptive system learns to proactively aid in generating appropriate strategies for any remanufacturing scenario that it is bound to encounter. While its performance may not be good at first during the learning stage, it gradually builds up its knowledge-base to incorporate the different kinds of defects it is likely to encounter in remanufacturing and the best possible solutions to address these shortcomings.

As a part of sustainable economy, remanufacturing process sometimes is called as closed loop recycling system. We consider products that have manufacturing defects with some missing or defective component, end-of-life used products that have some salvageable component parts in them and manufacturing byproduct into considerations. Remanufactured items are put on the market either as new or as refurbished. Most manufacturers treat remanufactured items that came from unused defective products as new and treat those from short-life products as refurbished.

Remanufacturing provides a closed loop environment where the amount of wastage is reduced. A side effect of this process is the availability of knowledge that help improve product quality by identifying problems in the manufacturing process by careful evaluation of returned products. Clearly, these problems do not necessarily result in dead on arrival (DOA) products. Instead, returned products (i.e., products found to be defective after being used for a short time period) contain very useful information both for quality management and for effective remanufacturing process. There are situations where the primary goal in manufacturing a product is not its long quality life-span. For instance, the marketing strategy might dictate the product life span to be set at a certain (relatively short) time for compulsory replacement. The proposed framework can be easily adjusted to learn and adapt to this scenario.

The remainder of this paper is organized as follows. We begin with literature review in Section 2. We present the dynamic remanufacturing framework in Section 3. We include several numerical examples to illustrate the presented model and its effectiveness. Section 4 concludes the paper with a brief discussion on the insights garnered and their implications.

2 Literature Review

Remanufacturing, reverse logistics, and recovery operations have been studied by researchers for at least during the past decade. For example, Goggin (1998) attempted to consider industrial practices to develop a theory on product recovery. Goggin (1998) developed typologies and models for product recovery operations based on typologies of manufacturing chains. Although remanufacturing, reverse logistics, and recovery operations have similar goals that attempt to address issues and constraints that are generally associated with reducing waste and effective use of products that are not perfect, they are not the same.

Rogers and Tibben-Lembke (1998) define reverse logistics as the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal." Other researchers have considered several facets of reverse logistics. For example, Fleischmann (2001) considers network design, inventory management, and production scheduling to develop models for optimizing each of those core operations. De Brito (2004) develops a framework for reverse logistics theory.

Product disassembly, a core area under product recovery management, is defined as an ecological approach that allows reusable, non-recyclable, and hazardous subassemblies to be selectively separated from recyclable ones (Seliger et al., 2001). According to Das, et al., (2000), key objectives of disassembly include (i) the recovery of valuable and reusable parts or subassemblies, (ii) product separation to facilitate the downstream material recovery process, (iii) the removal of hazardous or toxic materials, (iv) to remanufacture the product for another useful life, and (v) to destroy the proprietary parts of sub-assemblies. Given the importance of product recovery, several researchers have studied this problem in greater detail including Desai and Mital (2003), Feldmann and Scheller (1994), Gupta and McLean (1996), Lambert (2003). The interested reader is referred to these literature and the references therein.

3 Framework and Model

In general, product remanufacturing processes utilize end of life products, components, and materials with a purpose to recover as much of the economic (and ecological) value as possible, thereby reducing the ultimate quantities of waste. While the cost of remanufacturing also plays as one of the decision role for the management, how to improve efficiency and to reduce operational cost has become an eminent problem. We will investigate in this section the potential of utilizing RFID enabled adaptive learning system in remanufacturing process design.

3.1 Traditional View

Traditionally, remanufacturing starts from a normal manufacturing process, which produces a certain number of qualified products, a small portion of defective products (in some industry, such as plasma panel manufacturing, its number can be very significant), and some byproducts, Figure 1. The defective products, of which defects could be caused by various issues, are immediately put in the remanufacturing process that would try to recover value from these products. The end of life (EOL) products can be collected through different channel, such as consumer-retailer-manufacturer, consumer-manufacturer, consumer-third-party-manufacturer (Savaskan,Bhattacharya, and Van Wassenhove 2004). Both the defective and EOL products are diagnosed by technicians to identify the faulty components for further decisions.

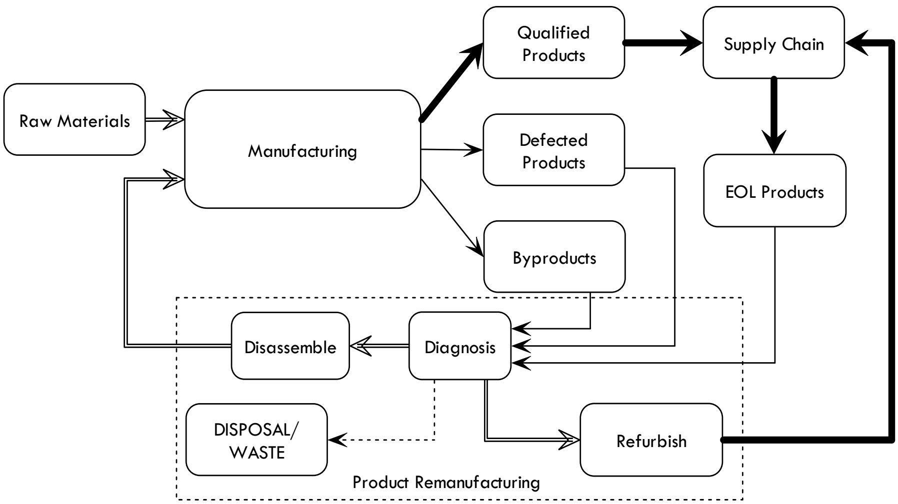

Fig. 1. Traditional product remanufacturing process

After collection, the products would go through several recovering procedures, which are usually implemented for remanufacturing that may include repairing and reusing, refurbishing, manufacturing, cannibalization and recycling (Thierry et al. 1995). The purpose of repairing and reusing is to fix used products to working order, which usually renders lower quality of the new products. Manufacturing using components from used/defective product is to bring used products up to quality standards that are as rigorous as those for new products by completely disassembling the products to the component level, accompanied by extensive inspection and replacement of broken/outdated parts. Refurbishing generally is characterized by first disassembling the product down to a preset module level, followed by inspection and replacement of broken modules. While discarding most of the components of a used/defective product, the procedure of cannibalization selects a small number of reusable parts and modules, which are usually of high value, from the used/defective products and uses these components/modules in manufacturing, repairing/reusing and refurbishing. Through separation processes, recycling involves collecting materials from used products, which are reused in the manufacturing of either the original or other products that shared the same materials.

Before Defective/EOL products can be restored for market, diagnosis and disassembly are usually performed and the operations of disassembly bring much uncertainty on planning, such as material resource planning, inventory management, shop floor control, production scheduling etc. After disassembly, parts are assessed as to their remanufacturability, within which those acceptable parts are then routed to the necessary operations. Parts not meeting minimum remanufacturing standards are disposed.

3.2 RFID Enabled Framework

Figure 2 illustrates the proposed product remanufacturing process with RFID and adaptive self-learning system, where we utilize artificial intelligence generated knowledge to assist selecting proper raw materials, configuring the normal manufacturing process and facilitating the diagnosis process. Integration of CRM and remanufacturing strategy (considering consumers' preference and perception on new, remanufactured, or refurbished products) could assist decision maker to gain insightful knowledge of the market and thus help establish the right market and manufacturing strategy.

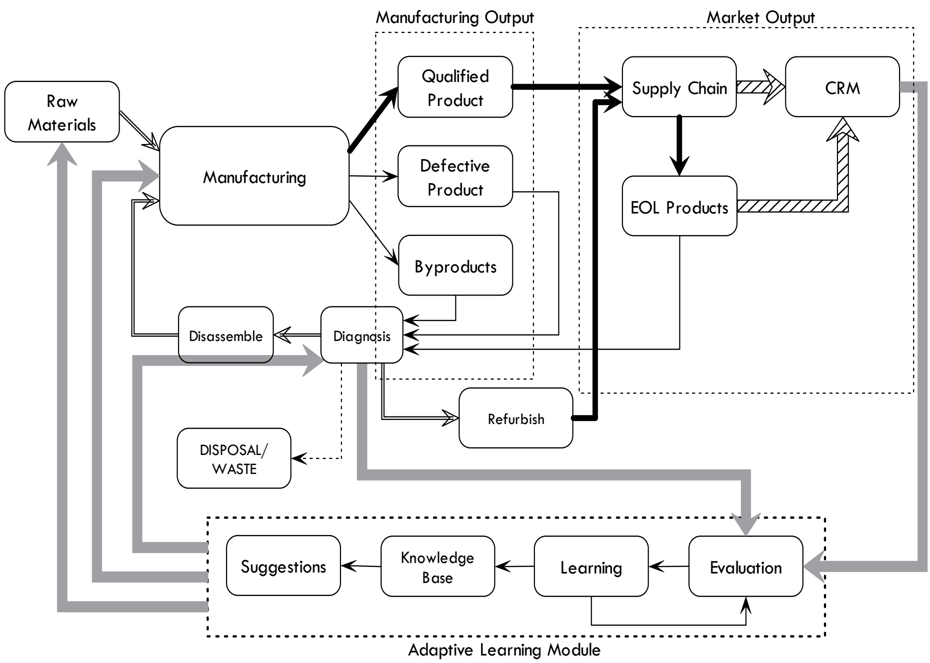

Fig. 2. Product remanufacturing process with RFID and adaptive self-learning system

Figure 3 illustrates a single manufacturing session with two sequential manufacturing processes. Raw materials are input at check point 1 in batch and are processed through P1 and P2. At check point 2, relevant characteristics of the products are measured and defective products are identified for further re-processing. Without RFID, all items are treated the same in throughout the manufacturing session and technicians would adjust the manufacturing configurations of both P1 and P2 based on information collected from check point 1 and check point 2, such that

Config(P1,P2)~F(ch1, ch2). With RFID real time item level information, we are now able to identify every single item at any time t, the associated characteristics of this item and possibly its ambient conditions. With refined continual information on individual parts throughout the session, the technician is able to fine tune the manufacturing processes for better quality, thus reducing the rate of producing defective products such that $Config(P1,P2) \sim F(ch1, ch2, ch_{RFID}(t))$.

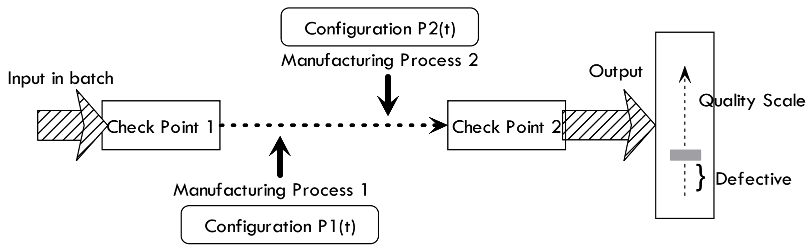

Fig. 3. Single manufacturing session with two sequential manufacturing processes

3.3 Adaptive Learning Module

The Adaptive Learning module is at the core of the proposed framework in facilitating the system to learn to adapt to dynamically changing environments. A majority of items that pass through the remanufacturing, reverse logistics and disassembly processes have disparate set of requirements depending on the number of component parts they have and the various ways in which these components can be compromised. This necessitates the system to possess the expertise to deal with the situation or at the least to gracefully (i.e., not break down in a brittle manner when faced with an entirely new situation) handle the situation based on partially similar situations it has encountered in the past.

The Adaptive Learning Module comprises four sub-components including the one for Learning, which learns necessary knowledge from products that have been remanufactured, disassembled or participated in reverse logistics earlier, Knowledge-base that contains knowledge obtained through learning, Evaluation for evaluating the resulting (e.g., remanufactured) product, and Suggestions for recommending the best possible course of action to take. These components act in consort to facilitate and accomplish the process of improving the performance of the system with time and experience as it recommends appropriate courses of action and learns of the resulting outcome.

Specifically, the Learning sub-component learns explicit and implicit patterns that are present in the domain (here, remanufacturing, disassembly, or reverse logistics) by using example scenarios that cover representative cases. The learned knowledge is then stored in the knowledge-base for later use when a similar pattern is witnessed in the system. Based on the instantaneous snap-shot of the system and any existing associated knowledge in the knowledge-base, the system suggests the best course of action. And, once this suggested course of action is implemented, the system waits to obtain more information on the outcome, which is then used to reinforce existing knowledge in the knowledge-base or learn new knowledge which can then be incrementally learned and incorporated in the knowledge-base. The Evaluation sub-component ensures and maintains the quality and completeness of the knowledge-base by enabling continual learning on the part of the Learning module by identifying existing deficiencies in the knowledge-base

The general steps that are involved in the proposed process can be summarized as follows:

1. Set evaluations interval (T)
2. Set initial values for raw material selection (R)
3. Set initial values for manufacturing parameters setting (P)
4. Repeat steps 5-11 until time T
5. Manufacturing begins. Specify local time (t). Set local-time=0.
6. If Reman(current configuration R) >> Reman(previous configuration R), go to step 8.
7. If local-time < t, go to step 6
8. Learning
9. If expected improvement(Δ(configuration)) > pre-determined threshold, go to 11
10. Else, go to step 4
11. Performance evaluation and Learning

3.4 Results and Analysis

We illustrate the benefits of implementing RFID-enabled real-time system in the context of manufacturing / remanufacturing by a numerical example. Consider a manufacturing session that consists of two manufacturing processes, as shown in Figure 3. After the raw materials are processed, there is a check point at the end of the manufacturing session that measures the characteristics of output products. However, depending on the process, we assume that there is no check point during the session. We consider the configuration of the first manufacturing configuration ($cnfg_1$) to be normalized and set to 10, which is subject to certain variance during the manufacturing process. The variance can be caused by uncertainties from external or internal sources so that at any given time point $cnfg_1$ can be 10.2, 9.9, etc., which is subject to a random distribution. While it is the same for the second manufacturing configuration, $cnfg_2$ that is set to 5, without real-time item-level tracing and tracking ability, the actual manufacturing information for the product is indeed missing. The general performance results of each individual manufacturing process as well as the quality characteristics of products at the check points, however, are available.

We consider the product quality at check point 2 as a direct result of the manufacturing configuration at the two processes, $Q\ (cnfg_1, cnfg_2)$. Without RFID information visibility, the quality of the output products can only be described by their aggregate statistical characteristics. Table 1 lists a set of sample numerical data for 12 products that go through the manufacturing session with two processes. Without RFID, while the only information available is the quality measurement at the check point, where the manufacturing configurations of processes 1 and 2 of each individual item are missing. With RFID real-time item-level information, we are able to obtain the following manufacturing history data for each product.

After analysis using the above data, we are able to identify certain patterns in the manufacturing session. For instance, product #3, 4, and 10's quality are below average, while historical data for those products show that both configurations 1 and 2 are below their pre-set levels which are 10 and 5 respectively. With these information and observation, we may conclude by saying that lower configuration on both manufacturing processes would result in a low quality product.

With RFID-generated information visibility and post-data-processing, we are able to obtain two possible benefits: 1. improve the manufacturing process, and 2. pinpoint possible quality issues related to individual defective products by considering its historical manufacturing data. Without RFID tracking and tracing ability, the information is based on statistical description at an aggregate level that deprives the ability to refine the manufacturing and remanufacturing process at an item level.

Table 1. Manufacturing history & quality data with two manufacturing processes

ID	$cnfg_1$	$Cnfg_2$	Quality
1	10.1	5.2	8.5/10
2	9.8	5.1	9.4/10
3	9.5	4.7	6.5/10
4	10.4	5.2	6.5/10
5	10.0	4.9	9.8/10
6	10.1	5.1	9.0/10
7	9.7	4.7	8.0/10
8	9.8	5.2	8.5/10
9	10.0	5.0	9.9/10
10	9.9	4.4	5.5/10
11	9.9	5.1	9.0/10
12	10.2	5.0	9.0/10

4 Discussion

We considered one of the problems faced by manufacturers with respect to dynamically adjusting manufacturing/remanufacturing process using a knowledge-based system framework. This process can be automated and operationalized in a seamless fashion through RFID-embedded component tags on individual parts. These RFID identified manufacturing parts also enable the quality manager to continually adjust manufacturing parameters at the item-level as is deemed necessary. We illustrated the proposed knowledge-based framework using heuristics. Preliminary results indicate that the manufacturer would benefited by such a framework and setup using RFID-generated information.

References

1. Das, S.K., Yedlarajiah, P., Narendra, R.: An approach for estimating the end-of-life product disassembly effort and cost. International Journal of Production Research 38(3), 657–673 (2000)
2. Desai, A., Mital, A.: Review of literature on disassembly algorithms and design for disassembly guidelines for product design. International Journal of Industrial Engineering: Theory Applications and Practice 10(3), 244–255 (2003)
3. de Brito, M.P.: Managing reverse logistics or reversing logistics management. PhD Dissertation, Erasmus University (2004)
4. de Brito, M.P., Parlikad, A.K.: Closed-Loop Supply Chain Management and Networked RFID - a Research Note (2005)
5. Feldmann, K., Scheller, H.: Disassembly of electronic products, pp. 81–86. IEEE, Piscataway (1994)
6. Goggin, K.: Modeling end-of-life product recovery, PhD Dissertation, National University of Ireland (1998)
7. Gupta, S.M., McLean, C.R.: Disassembly of products. Computers & Industrial Engineering 31(1-2), 225–228 (1996)
8. Lambert, A.J.D.: Disassembly sequencing: A survey. International Journal of Production Research 41(16), 3721–3759 (2003)
9. Thierry, M.C., Salomon, M., van Nunen, J.A.E.E., Van Wassenhove, L.N.: Strategic issues in product recovery management. California Management Review 37(2), 114–135 (1995)
10. Tibben-Lembke, R.S., Rogers, D.S.: Differences between forward and reverse logistics in a retail environment. Supply Chain Management 7(5) (2002)
11. Seliger, G., Keil, T., Rebafka, U., Stenzel, A.: Flexible disassembly tools, pp. 30–35. Institute of Electrical and Electronics Engineers Inc., Denver (2001)
12. Piramuthu, S.: Knowledge-based framework for automated dynamic supply chain configuration. European Journal of Operational Research 165(1), 219–230 (2006)
13. Wei, Z.: RFID and item-level information visibility. European Journal of Operational Research 198(1), 252–258 (2009)