IMPACT OF CANNIBALIZATION IN A REMANUFACTURING SUPPLY CHAIN

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Abstract

Using a Bass Diffusion model we investigate the effect of cannibalization within a hybrid manufacturing /remanufacturing/refurbishing system. The hybrid system consists of newly manufactured products, remanufactured products, and refurbished products. The impact of the collection, remanufacturing, and refurbishing ratios on economic performance are simulated and analyzed. We numerically calculate profit and investigate the relationship between the demand for manufactured and remanufactured products. We conclude that the proposed hybrid manufacturing/remanufacturing/refurbishing model can evaluate the cannibalization effect quantitatively and that the hybrid manufacturing/remanufacturing/refurbishing system is more profitable than a non-remanufacturing system, even when cannibalization is present.

Keywords: Closed loop supply chain, Hybrid manufacturing/remanufacturing/refurbishing, Cannibalization.

1 INTRODUCTION

Japan has undergone an extended period of economic growth based on mass production, consumption, and disposal. As a result, the country is suffering from resource depletion and environmental problems. Now companies are striving to reduce the environmental impact and resource consumption of their manufacturing activities. Operating a closed-loop supply chain (CLSC) system is one way to accomplish this. However, there are not many quantitative studies of the profit potential of closed loop manufacturing/remanufacturing systems. This is a concern because companies may not wish to operate in situations when they are unsure of the economic consequences.

Most CLSC studies relate to manufacturing and remanufacturing, but do not consider the refurbishing activities. Refurbished products are those that have been lightly used or slightly damaged and quickly repairable for resale. In this study we propose a hybrid manufacturing/ remanufacturing model consisting of manufacturing, remanufacturing, and refurbishing. Our model incorporates ratios for collecting, remanufacturing, and refurbishing. We conduct numerical experiments to ascertain the profitability of the system.

We also examine the relationship between the demand for manufactured and remanufactured products. If a company remanufactures used products into as-good-as-new products and sells only new products, it is not necessary to examine the relationship between the demands for original and remanufactured products. However, if the company sells the remanufactured products separately from the new products, this hybrid manufacturing/remanufacturing system needs to account for cannibalization and market expansion effects. It is important to understand the consequences of these two effects when developing efficient CLSC. Therefore, we investigate these two effects in our hybrid manufacturing/ remanufacturing model.

2 LITERATURE REVIEW

Many studies have considered hybrid manufacturing/ remanufacturing systems. Wang et al., (2011) investigated a hybrid manufacturing/remanufacturing model with stochastic demands and collection ratios so as to minimize the total cost of the system. Kenne et al.,

(2012) studied production scheduling and inventory control in a hybrid manufacturing/remanufacturing setting. Neto et al., (2012) compared new products to remanufactured products via customers' willingness to pay and energy consumption. Qiang et al., (2013) examined the investment required for establishing the collection of the used product. Qiang et al., (2014) demonstrated the impact of design for remanufacturing and the consumers' perception of the remanufactured product on profitability and market share. These studies considered only manufacturing and remanufacturing; they excluded an analysis of the refurbishing activities.

In a study of product life cycles within a hybrid manufacturing/remanufacturing system, Umeda et al., (2006) proposed an index termed 'marginal reuse rate' that showed that successful reuse depends on the product life cycle. Geyer et al., (2007) demonstrated that remanufacturing cost savings are related to the life cycle and durability of the product. Atasu et al., (2008) considered the profitability of remanufacturing over the product life cycle highlighting the product life cycle plays a critical role in the development of a successful CLSC system.

Souza (2012) shows that remanufactured products have two implications in consumer demand: 1) a market expansion effect, and 2) a cannibalization effect. The cannibalization effect is often accused of reducing profit as it suppresses the demand for new products. However, Atasu et al., (2010) argued that remanufactured products can enable additional market segments to be reached. Guide et al., (2010) also asserted that examination of the cannibalization effect is necessary in CLSC studies.

Gallo et al., (2009) proposed a model where remanufactured goods were sold in a second market. They simulated scenarios that consider collection ratios and the quality of the collected product and investigate the profit of hybrid manufacturing/remanufacturing system. However, this study did not examine the cannibalization effect because remanufactured products were deemed to be separate from new products. The model proposed in this study examines the relationship between the demand for manufactured and remanufactured products in a hybrid manufacturing/remanufacturing system.

Building upon Fourt et al., (1960) and Mansfield (1961), Bass (1969) created what has now become known as the

Bass diffusion model to represent demand over the product life cycle. The Bass diffusion model considered the adoption of new products using innovator and imitator characteristics. Oshita et al., (2009) proposed a cascade reuse model and optimal ordering policy of new and reused parts in hybrid manufacturing/remanufacturing systems based on the Bass model. We extend this line of inquiry by examining market expansion and the cannibalization effects on the demand for new and remanufactured items in a Bass diffusion model.

3 THE MODEL

Figure 1 provides a schematic of our model. We see that, in the manufacturing stage, new products consume raw materials. At the remanufacturing stage, returned products are inspected and classified according to their condition. Returned products are classified into three groups: remanufacturing, refurbishing, and disposal. New products, remanufactured products, and refurbished products are defined below:

(1) New products. Products that use all new raw materials and parts.
(2) Remanufactured products. Products collected from the market that are disassembled, inspected, washed, repaired, reassembled, and remanufactured.
(3) Refurbished products. Products that are have been briefly used (i.e. display models) or have minor damage that is cleaned, repaired, and sold as new.

Refurbishing can be thought of as small-scale remanufacturing. Refurbished products are sold as new, but remanufactured products are different from new and refurbished products.

Our baseline model is dynamic but essentially deterministic. The *raw* demand (before any cannibalization has occurred) for new products is given by the Bass (1969) diffusion model,

$$D_t^N = m_N \cdot \frac{(p+q)^2}{p} \cdot \frac{e^{-(p+q)t}}{\left(1+\frac{q}{p}e^{-(p+q)t}\right)^2}, \tag{1}$$

where $t \in \mathbb{N}_0$ is a discrete (periodic) time index, m_N is the ultimate size of the market potential for new products, p is the coefficient of innovation, and q is the coefficient of imitation. We assume the remanufactured demand is also given by a Bass (1969) diffusion model,

$$D_t^R = \begin{cases} 0 & \text{if } t < \Delta t \\ m_R \cdot \frac{(p+q)^2}{p} \cdot \frac{e^{-(p+q)(t-\Delta t)}}{\left(1+\frac{q}{p}e^{-(p+q)(t-\Delta t)}\right)^2} & \text{if } t \ge \Delta t, \end{cases} \tag{2}$$

where m_R is the ultimate market potential for remanufactured product and Δt is the delay factor that shifts the demand the remanufactured product into the future. Note, we assume here p and q are the same for both the new and remanufactured demand; the two demands have the same shape, they are just shifted and scaled differently. We defer the case when the two Bass coefficients take different values for future work. The remanufactured demand cannibalizes some of the new demand. We assume the proportion, $\alpha \in (0,1)$, of the remanufactured demand has cannibalized the new demand, and the remaining, cannibalized demand for new items is,

$$D_t^{NC} = \left(D_t^N - \alpha D_t^R\right)^+. \tag{3}$$

Here $(\cdot)^+$ is the maximum operator, i.e., $(x)^+ = \max(x,0)$. The total demand in a period is then given by

$$D_t^T = D_t^R + \left(D_t^N - \alpha D_t^R\right)^+. \tag{4}$$

A proportion, r, of the total demand is collected as returns in period t,

$$v(t) = rD_t^T. \tag{5}$$

A portion of the returns, μ_{RF}, are refurbished at a unit cost of CR^{RF}. The quantity refurbished, w_t^{RF}, is given by

$$w_t^{RF} = \mu_{RF}v(t). \tag{6}$$

A proportion of the collected returns, μ_R, are disassembled and remanufactured at a unit cost of $\left(CR^{DA} + CR^{RM}\right)$. The amount remanufactured, w_t^R, is given by

$$w_t^R = \mu_R v(t). \tag{7}$$

The returns that are neither refurbished nor remanufactured are disposed in a landfill at a unit cost of C_t^D. The quantity disposed of in each period is,

$$w_t^D = \left(1 - \mu_R - \mu_{RF}\right)v(t). \tag{8}$$

The remanufactured items are then placed in inventory and used to satisfy the demand for remanufactured items. (Initially, there is no demand for remanufactured items, so this inventory grows in an uncontrolled manner; it will be depleted later). The remanufactured inventory evolves via the following balance equation,

$$I_t^R = I_{t-1}^R + w_t^R - D_t^R + T_t, \tag{9}$$

where T_t are the transfers in period t. Transfers are new products that are used to satisfy remanufactured demand in periods when there is insufficient inventory to meet remanufactured demand. We can apply the inventory holding, C_t^H, to $\left(I_t^R\right)^+$, and backlog costs, C_t^B, to $\left(-I_t^R\right)^+$. The inventory of new and refurbished items at the beginning of the period, the opening inventory, OI_t^N, is given by,

$$OI_t^N = EI_{t-1}^N + w_t^{RF} - T_{t-1} - D_t^N. \tag{10}$$

Here EI_t^N is the ending inventory in period t. Production of new items is determined by,

$$w_t^N = \left(tns^R - I_t^R\right)^+ + \left(tns^N - I_t^N\right)^+, \tag{11}$$

where; the first addend, $\left(tns^R - I_t^R\right)^+$, brings the inventory of remanufactured items *up-to* the target net stock for remanufactured items tns^R, and the second addend, $\left(tns^N - I_t^N\right)^+$, brings the inventory of new items *up-to* its target net stock. There is a lead-time of one period to produce the newly manufactured items; the completions are thus,

$$c_t^N = w_{t-1}^N \tag{12}$$

and the ending inventory of newly manufactured (and refurbished items) is given by

$$EI_t^N = OI_t^N + c_t^N. \tag{13}$$

The transfer of new items, used to satisfy demand for remanufactured items when there is insufficient inventory to satisfy remanufactured demand is given by,
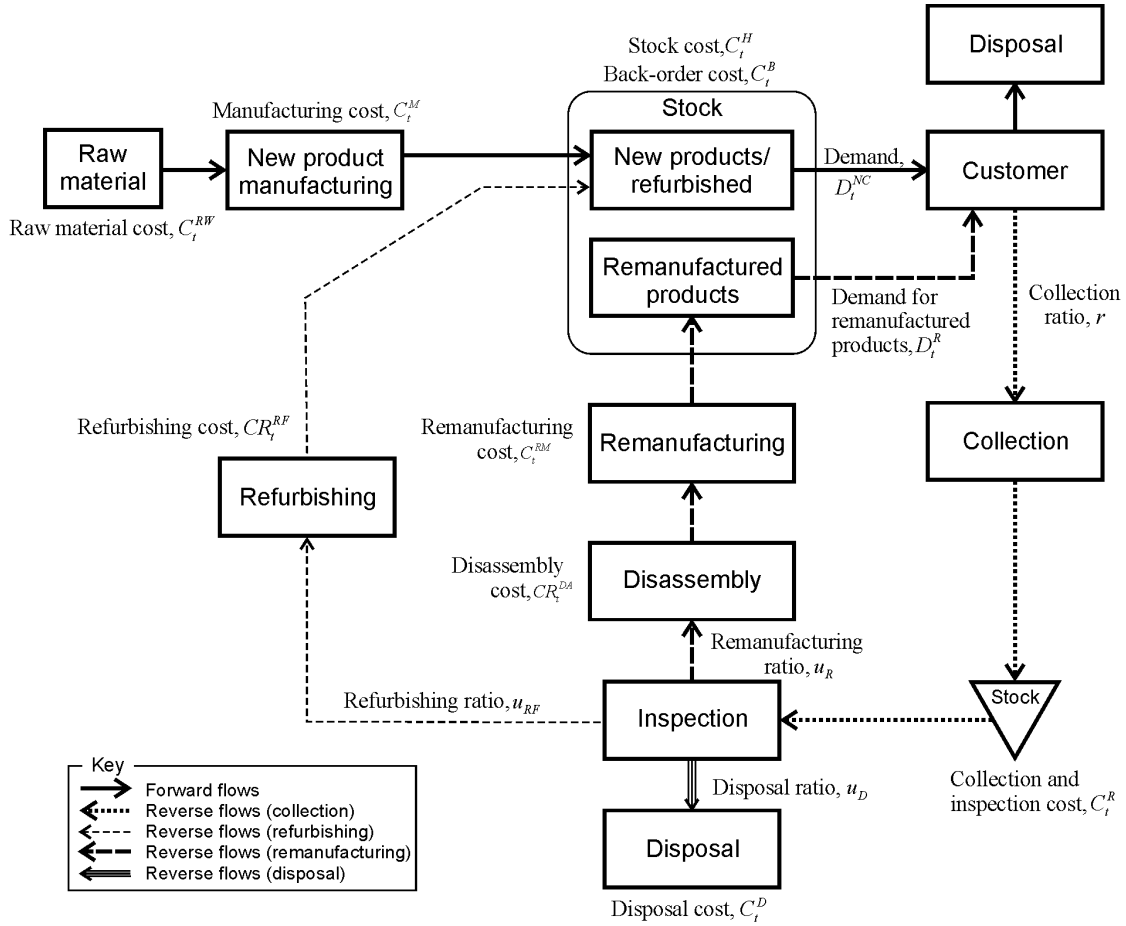
Figure 1. Schematic of our hybrid manufacturing/remanufacturing model

$$T_t = \min\left\{\left(tns^R - \left(I_{t-1}^R + w_t^R - D_t^R\right)\right)^+, \left(EI_t^N\right)^+\right\}. \quad (14)$$

Remaining is the inventory of new and refurbished items after any transfers to the remanufacturing inventory, $EIAT_t^N = EI_t^N - T_t$. $\quad (15)$

Finally, we apply the unit inventory holding, C_t^H, to $\left(EIAT_t^N\right)^+$ and unit backlog costs, C_t^B to $\left(-EIAT_t^N\right)^+$.

4 THE DYNAMIC RESPONSE OF OUR SYSTEM

The relationship between the demand for newly manufactured products and remanufactured products will now be analyzed using the numerical setting detailed in Table 1. Our modeling choices have been based on a supply chain for personal computers as many of their components have potential for recycling. It is expected that the number of personal computers being disposed of will increase in the next few years. Furthermore, since the Basic Law for Establishing the Recycling-based Society has been introduced and enforced in Japan, the quantity of remanufactured items that are collected from the marketplace is expected to increase.

Figure 2 plots the demand for new and remanufactured products. We can clearly see the influence of the innovators and imitators in the demand for new products. We can also see the delayed response for remanufactured products, the cannibalization effect, and the market expansion effect.

Figure 3 plots the total demand (the line) together with a stacked plot of the fate of the collected returns, $v(t)$, (the

shaded areas). A proportion, μ_D, of the returns are sent to the landfill at the unit cost of CR_t^D. A proportion, μ_{RM}, of the returns are disassembled and remanufactured at the cost of $CR_t^{DA} + CR_t^{RM}$. A proportion of the returns, μ_{RF}, are refurbished at the unit cost of CR_t^{RF} and join the new product inventory. The white area represents the products that either remain in use, or have been disposed of, by the customer.
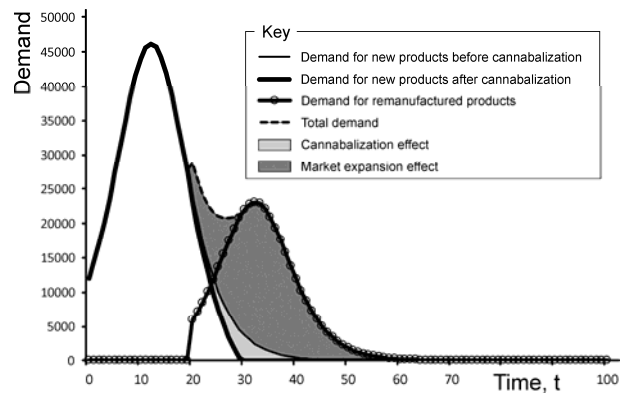

Figure 2. Demand model

Figure 4 provides a sketch of the evolution of the inventory levels. Initially, the inventory of new items fluctuates around the target net stock, occasionally going into backlog, other periods end with a stock holding.

Variable	Description	Numerical value
P_N	Sales price of a new or refurbished personal computer	¥ 100K
P_R	Sales price of remanufactured personal computer	¥ 60K
p	Coefficient of innovation	0.015
q	Coefficient of imitation	0.2
m_N	Market potential for new products	800K
m_R	Market potential for remanufactured products	400K
Δt	Delay factor	20
α	Cannibalization ratio	0.2
r	Collection ratio	0.3
μ_R	Remanufacturing ratio	0.4
μ_D	Disposal ratio	0.3
μ_{RF}	Refurbishing ratio	0.3
CR_t^R	Collection cost	20
CR_t^{DA}	Disassembly cost	5
CR_t^{RM}	Remanufacturing cost	15
CR_t^D	Disposal cost	5
CR_t^{RF}	Refurbishing cost	5
tns^R	Target net stock of remanufactured items	100
tns^N	Target net stock of new items	100
C_t^H	Inventory holding cost	1
C_t^B	Backlog cost	9
C_t^M	Manufacturing cost	30
C_t^{RM}	Raw material cost	20
T	Simulation time horizon	100

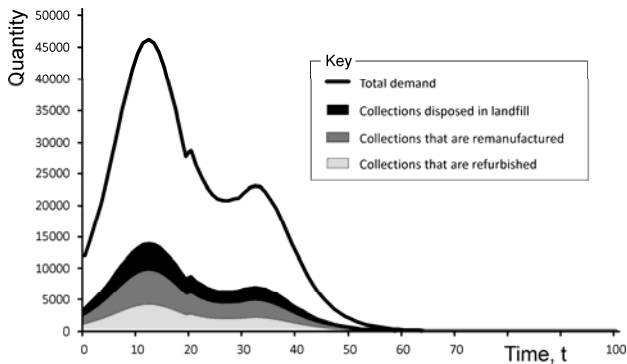Table 1. Numerical settings in our simulation study

Figure 3. Fate of the collected returns

Meanwhile, the inventory of returned and remanufactured items grows unchecked until the demand for remanufactured product is activated. At this point of time, the inventory of remanufactured item declines. Shortly after the collected returns are insufficient to satisfy remanufactured demands, so new products are manufactured (the transfers) to be sold as remanufactured items. If α or r becomes large, more returns exist than the demand for remanufactured products and the system suffers from holding a significant amount of stock in perpetuity.
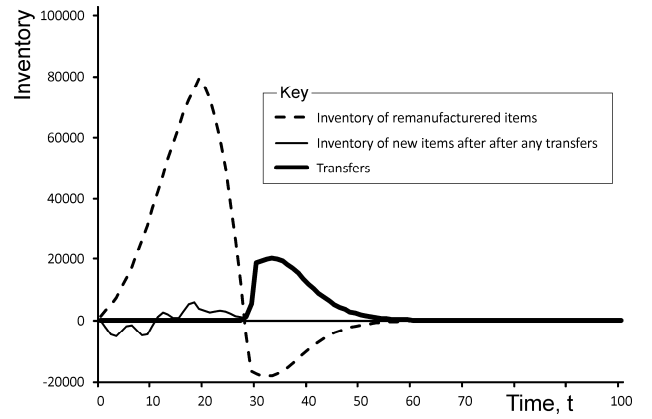

Figure 4. Inventory profiles

5 EXPECTED PROFIT

We assume that the new and refurbished product sales price is different than the remanufactured product selling price. Bringing together (5), (6), (7), (9), (11) and (15) the expected profit from our hybrid manufacturing/remanufacturing system over the simulation horizon of T time periods is given by,

$$\Pi = \sum_{t=1}^{T} \left(\begin{array}{l} P_N D_t^{NC} + P_R D_t^R \\ \left(\left(C_t^{RM} + C_t^M \right) w_t^N + C_t^H \left(\left(I_t^R \right)^+ + \left(EIAT_t^N \right)^+ \right) + \right) \\ - \left(C_t^B \left(\left(-I_t^R \right)^+ + \left(-EIAT_t^N \right)^+ \right) + v(t) CR_t^R + \right) \\ + w_t^R \left(CR_t^{DA} + CR_t^{RM} \right) + CR_t^{RF} w_t^{RF} \end{array} \right). \quad (16)$$

Based on (16) numerical experiments were executed to confirm the profitability of the manufacturing/ remanufacturing system.

Figure 5 highlights the market expansion effect via the relationship between the collection ratio and profit. We can see that overall profit increases as more products are returned from the marketplace until the system reaches a tipping point. This tipping point occurs when there are so many returns that the remanufacturing demand cannot absorb the inventory created. This indicates that the company should take care near the end of a product's life cycle so as to not be burdened with unwanted returns.
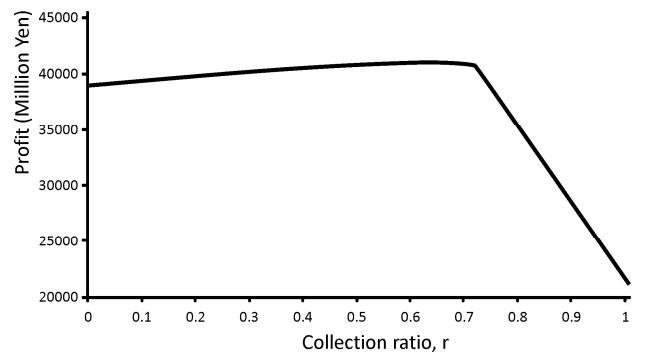

Figure 5. The impact of the collection ratio on profit

Figure 6 highlights the impact of the cannibalization on profit via the cannibalization ratio α. We can see that as it becomes more likely that remanufacturing demand reduces the demand for new products, then profit decreases.
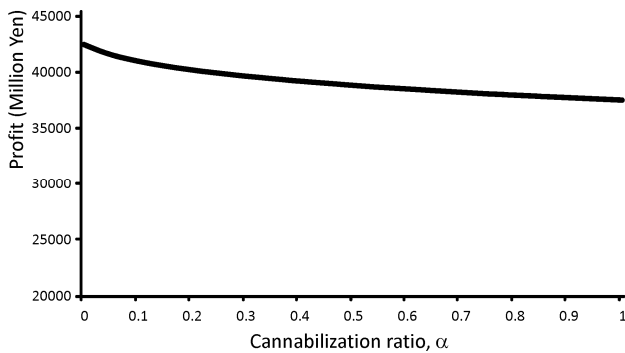
Figure 6. The impact of the cannibalization on profit

Figure 7 highlights the impact of the refurbishing ratio and the remanufacturing ratio on profit. We can see that as more items are refurbished, rather than remanufactured then the profit increases.
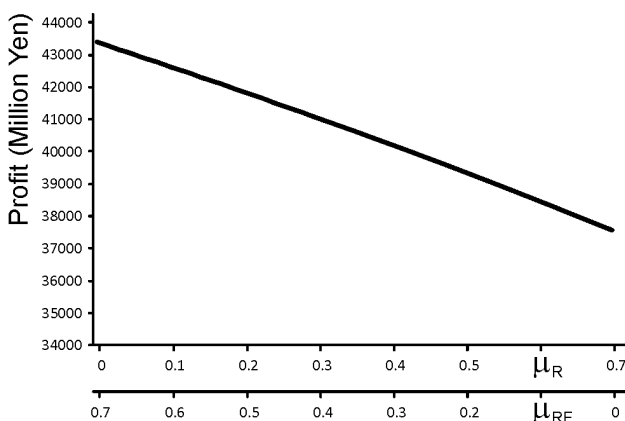

Figure 7. Impact of refurbishing on profit

4   CONCLUSION

In this study, a hybrid manufacturing/remanufacturing/ refurbishing CLSC model has been proposed. A scenario was simulated based on the supply chain for personal computers. The results indicate that the hybrid manufacturing/remanufacturing/refurbishing model is more profitable than one that did not include refurbishing. The model was evaluated using different values of key parameters. Furthermore, the demand model used in this study clearly shows the relationship between the demand for newly manufactured products and the demand for remanufactured products. For future research, we plan to consider the impact of characteristics such as product quality shelf life and the stage in the product life cycle.

5   ACKNOWLEDGEMENT

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