Inventory Model for Remanufacturing

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The global demand for consumer electronic products has been phenomenal in the last two decades. The negative environmental effects of the growing consumption of electronic hardware are most visible in the end-of-life (EOL) stage. Remanufacturing is a viable option in electronic waste management as it reduces e waste generation and increases reuse of equipment and components. Inventory control in remanufacturing requires appropriate control mechanisms to integrate the return flow of used products with the material planning for the forward flow. The mechanism is different for remanufacturing or reuse, where used products are returned for introduction into the main production stream. In this case, returned goods are an additional inventory source to the usual inventory procured from outside. Moreover, this additional flow is not directly available to the manufacturer because of the unpredictable quantity, time and quality of products that will be returned from the customers. The paper aims at generating a mathematical model for minimizing the inventory cost by increasing the returns. This is done by controlling the return index by introducing two factors namely Customer behavior and service agreement with the customer.

Key words: Remanufacturing, inventory, complexity, return index, cost.

INTRODUCTION

Remanufacturing refers to getting the used product to as good as new conditions. Cell phones, laptops are good remanufacturing options. Here a reverse supply chain integrated with the forward supply chain, in effect forming a closed loop supply chain is considered. Several factors influence the system and some of the more important factors are selected for this paper. The factors that influence Return rate, one of the main factors that influence the quantity and timing of returns, which happen to be two of the three main uncertainties in returns, the other being quality, is found out using causal flow diagram (Barlas, 1996). A few assumptions are made in this study for convenience sake. Single product remanufacturing alone is considered, Pull inventory control is considered, a return rate depending on the uncertainty in the quantity of returns is considered, also it is assumed that the demands and returns are correlated, uncontrolled disposal is not considered. Collection remanufacturing and production are considered infinite.

LITERATURE REVIEW

The concept of reverse logistics is gaining significant attention from within the realms of academia and industry. Returns rate is one of the main reverse logistics factors affected by uncertainty in timing and quantity of returns (Angerhofer and Angelides, 2000). A System Dynamics simulation tool was developed to analyze the dynamic behavior and the influence of the various activities on the reverse logistics network. In particular, the objective of the research was to simulate a remanufacturing feedback loop to determine the effect of remanufacturing capacities and penalties on total costs under various scenarios. Penalties refer to an inappropriate collection and handling of used products imposed on companies by environmental legislation. It was found that total costs decreases when higher remanufacturing capacities are reached (Coyle, 1996). In another similar study using System Dynamics, the impact
of environmental influences and remanufacturing capacity planning policies were simulated on the behavior of a reverse logistics system (Georgiadis and Vlachos, 2004a). They analyzed the effects of customer awareness of a company’s green image on product demand and the environmental legislation on the collection rate of returns flow. The activities modeled in their systems included: supply, production, distribution, usage, returns collection, inspection, remanufacturing and waste disposal.

Inventory control in closed loop supply chain

Inventory control is a fundamental activity in closed loop supply chains, particularly for remanufacturing processes. Several models have been developed in the literature where the aim is mostly to optimize cost or profit and to find the optimal order quantity for an integrated production and remanufacturing system (Tang et al., 2007). Due to the uncertainties in remanufacturing, the inventory costs are affected the most because of the fluctuating nature of the returns. Also from the time measurement it can be found out that the maximum time spent by the return is at the inventory. Hence it is very important that the time spent in the inventory and the inventory costs should be controlled [6]. This can be done by increasing the returns and through prompt remanufacturing, thereby reducing the time that the returns spent in the recoverable inventory and thus reducing the holding cost, which will eventually lead to overall reduction of the inventory cost. From the literature review it has been identified that in order to control the returns the obvious solution is to control the return index (Teunter, 2001. Hence by controlling the return index we can control the returns. In order to control the return index two new factors have been introduced. One is the SERVICE AGREEMENT WITH CUSTOMER and the other is the CUSTOMER BEHAVIOUR

METHODOLOGICAL APPROACH

A System Dynamics approach as a modeling and simulation method for dynamic industrial management processes could be an excellent tool for those management systems in which new decisions have to be made and new circumstances appear with the passing of time. A causal loop diagram (CLD) assists in the understanding of system structure as it identifies the important factors and variables influencing a system as well as the causal influences among these variables. A CLD consists of variables connected by arrows denoting the hypotheses and the mental models of the modeler in order to represent the feedback structure of systems which are responsible for a problem. Positive as well as negative feedback interrelationships can be represented through feedback or causal loops. The influence between variables is indicated by the + and – signs which show how the dependent variable changes when the independent variable changes. In order to study the quantitative view of the model, a Stock and Flow Diagram (SFD) is used to represent the process. Through the SFD, it is possible to analyze the dynamic characteristics between rate and level variables and define the relationships among the variables of the model. These relationships are used to establish mathematical equations in order to run simulations of the model.

CAUSAL LOOP DIAGRAM

The Causal Loop Diagram is similar to the one used earlier. However it can be seen that the return index is influenced by the CUSTOMER BEHAVIOUR and the SERVICE AGREEMENT WITH THE CUSTOMER. The behavior of the system is defined by seven negative feedback loops labeled as N1, N2, N3, N4, N5, N6 and N7. These loops balance the system and push typical
production and remanufacturing factors towards stable levels rather than causing them to grow exponentially. Negative feedback loops operate to control the output of activities in order to bring the state of the system towards a target value. The behavior of the collection section is represented by loops N1 and N2. An increase in returns increase the rate of collection which in turn increases the collected returns which returns entry at gate keeping and increases the return accumulation in Sorting/Storing. At sorting/storing two feedback loops are operating. Negative feedback loop N1 involves sorting/storing and inspection/failure. If the returns at sorting/storing increase then the rejection number goes up increasing the disposal. The amount of disposal is positively influenced by the percentage of disposal. The percentage represents the quality standard policy of the company and depends upon several other factors. Now an increase in the inspection/failure leads to the decrease in Sorting/storing a negative feedback loop is created.

The negative feedback loops N3 and N4 represent the remanufacturing activity. The remanufacturable items are stored in the recoverable inventory and the items that have been remanufactured are stored in the serviceable inventory.

Negative feedback loop N5 creates a balance between production flow and serviceable inventory levels. The negative feedback loop N6 involves production, remanufacturing, recoverable inventory, serviceable inventory.

The negative feedback loop N7 is between used products and returns, several variables also affect this loop. As demand increases the serviceable inventory level decreases. The demand depends upon the demand look up. Uncertainty in the quantity of used products returned by customers negatively affects collection, remanufacturing and production planning. For this reason, several variables are used to reduce the effect of uncertainty and set the quantity of returns. The return index, related to SERVICE AGREEMENT WITH THE CUSTOMER and CUSTOMER BEHAVIOUR is used to set the number of possible returns from the customer.

- **SERVICE AGREEMENT WITH THE CUSTOMER** defines the percentage of service agreement or incentives that the company offers to the customer at the end or during the use of the product in order to stimulate the return process. However, it could also represent the percentage of responsibility that the company has towards the recovery of its own products.
- **CUSTOMER BEHAVIOUR** defines the attitude of the customers in returning used products and their response to the company incentives in increasing the return process.

This theoretical influence analysis is used to involve as much as possible the relationship between customer behavior and quantity of returns.

**STOCK AND FLOW DIAGRAM**

The Stock and Flow diagram for inventory model is also similar to the one used previously. It can be seen that the return index is no longer influenced by the residence time, but the CUSTOMER BEHAVIOUR and the SERVICE AGREEMENT WITH THE CUSTOMER. In order to give a quantitative point of view to the model, a stock and flow diagram (SFD) is used to study the characteristics of the process. Through the SFD, it is possible to analyze the dynamic characteristics between rate and level variables and define the relationships among the variables of the model. Rectangles represent level or stock variables which are accumulations of items while valves represent rate or flow variables which are physical flows of items feeding or depleting the stocks. Physical flows of items are represented by double line with arrows while flows of information are represented by single line with arrows.

From the diagram it can be found that the stock variables are Disposal, Sorting/Storing, Recoverable inventory, Serviceable inventory, Collected Returns, Used Products, and Returns accumulations. Flow variables are percentage of disposal, inspection/failure, inspection/acceptance, collection, gate keeping, Remanufacture up to level, low level of serviceable for remanufacturing, production up to level and low level of serviceable for production, demand, demand look up, Residence time, demand inflow, returns, return rate, returns inflow, return index, demand forecast, initial demand, smoothing constant. From the SFD the relationship between the various factors can be derived.

**MATHEMATICAL FORMULATION**

The dynamic behavior of the remanufacturing system is implemented by a set of mathematical equations that has been obtained from the stock and flow diagrams. The dynamic behavior of the Stock variables is obtained by a time integral of the net inflows minus the net outflows. The model developed has been shown below.

Return index is obtained from the graph drawn using the values of customer behavior, and Service agreement with the customers.

The returns inflow is obtained from the demand and return index.

- **Returns inflow** $(t) = \text{demand} (t) \times \text{return index} (t)$
  
  The returns rate depends on the returns inflow and demand.
- **Returns Rate** $(t) = \text{returns inflow} (t) / \text{demand} (t)$

The returns depend upon the used products, returns rate and the return time.

- **Returns** $(T_x) = \text{Used Products} (t) \times \text{Returns Rate} (t) / \text{demand} (t)$

- **Returns inflow** $(t) = \text{demand} (t) \times \text{return index} (t)$
RETURN TIME

Demand inflow is obtained using a delay fixed function

- \( \text{Demand inflow} = \text{DELAY FIXED (demand, residence time, 0) } \)
- \( \text{Used Product} = \int [\text{returns (t) } - \text{demand inflow (t)}] \)
- \( \text{Demand (t)} = \text{Demand lookup (time)} \)

The production reorder and remanufacturing order depends upon the recoverable and serviceable inventory level. The following conditions have been employed to control the production reorder and remanufacturing order.

- If \((\text{serviceable inventory} < \text{low level of serviceable for production}) \text{ and } (\text{Recoverable inventory} \leq \text{(low level of serviceable for remanufacturing + Remanufacturing up to level)})\)
  - Production = production upto level- serviceable inventory
  - Remanufacture (t) = Remanufacturing up to level- Low level of serviceable for Remanufacturing
  - Remanufacture = 0

As mentioned earlier the stock variables like recoverable inventory, serviceable inventory, collected returns and sorting/storing are obtained by integrating the net inflows minus the net out flows.

Recoverable inventory \( (t) = \int \text{inspection/acceptance (t)} - \text{remanufacturing} \)

- Serviceable inventory \( (t) = \int \text{Remanufacturing (t)} + \text{Production (t)} - \text{Demand (t)} \)
- Sorting/Storing \( (t) = \int \text{Gatekeeping (t)} - \text{Inspection/Failure (t)} - \text{Inspection/Acceptance (t)} \)
- Collected Returns = \( \int \text{Collection (t)} - \text{Gate Keeping (t)} \)

Failed returns are given by the multiple of percentage disposal and the returns in the sorting/storing at the given time. Similarly the accepted returns are obtained from a similar relationship with percentage of acceptance.

- \( \text{Inspection / Acceptance (t)} = \frac{\text{Sorting / Storing} \times (1- \text{Percentage of disposal})}{\text{Percentage of disposal}} \)
- \( \text{Inspection / Failure (t)} = \frac{\text{Sorting / Storing} \times \text{Percentage of disposal}}{\text{Percentage of disposal}} \)

The percentage of remanufacturing is the formula used by Georgiadis, Vlachos in ‘Decision making in reverse logistics using system dynamics’.

- \( \text{Percentage of remanufacturing} = \frac{1}{(1 + e^m)} \)
  - \( M = \frac{a_2 \times (C_{\text{Remanufacturing}} \times C_{\text{Disposal}})}{C_{\text{Production}} } \)

The returns are considered equal to the collection time that is collection capacity is assumed to be infinite.

- \( \text{Returns (t)} = \text{Collection (t)} \)

For calculating the inventory costs, the factors, setup costs, Holding costs and Cost of Stock Out are included. The aim here is to reduce inventory cost by reducing the holding cost in the recoverable inventory.

Rate of remanufacturing and Production has not been
Table 1: Data obtained from a firm

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Setup Costs per reorder</td>
<td>10000</td>
</tr>
<tr>
<td>Unit cost for lost sale</td>
<td>25000</td>
</tr>
<tr>
<td>Recoverable inventory holding cost per item</td>
<td>3</td>
</tr>
<tr>
<td>Serviceable inventory holding cost per item</td>
<td>6</td>
</tr>
</tbody>
</table>

**Figure 3. Inventory fluctuations over time**

considered hence remanufacturing and production does not affect the inventory costs.

- **Setup Costs = Sum of fixed Costs per reorder.**
- **Cost of stock out = Unit cost for lost sale * no. Of lost sales**
- **Holding Costs = recoverable inventory * Recoverable holding cost per item + Serviceable Inventory * Serviceable holding cost per item.**
- **Total Inventory Costs = Collected Returns + Setup Costs + Cost of stock out**

**LINEAR PROGRAMMING**

A linear programming problem may be defined as the problem of maximizing or minimizing a linear function subject to linear constraints. The constraints may be equalities or inequalities. From the mathematical model a linear programming to minimize the inventory cost has been developed. Here the linear function under consideration is the inventory cost and the constraints provided are explained.

\[
\text{MIN } Z = X_{FS} + X_{NFS} + X_{LS} + X_{U.S.L} + X_{RIQ} + X_{SIQ} + X_{RHC} + X_{SHC}
\]

Subjected to,

1) \(FS \times X_{FS} + NFS \times X_{NFS} <= SC\)
2) \(LS \times X_{LS} + USL \times X_{U.S.L} <= SO\)
3) \(RIQ \times X_{RIQ} + SIQ \times X_{SIQ} + RHC \times X_{RHC} + SHC \times X_{SHC} <= HC\)

Where,

- \(Z\) = Total Inventory Cost
- \(SC\) = Setup Costs
- \(SO\) = Cost of Stock Out
- \(HC\) = Holding Costs
- \(X_{FS}\) = Coefficient for fixed setup costs per reorder
- \(FS\) = Fixed Setup Costs
- \(X_{NFS}\) = Coefficient for number of Fixed Setup Costs
- \(NFS\) = No. Of fixed Setup Costs
- \(X_{LS}\) = Coefficient for No. Of Lost Sales
- \(LS\) = Number of lost Sales
- \(X_{U.S.L}\) = Coefficient of Unit Cost for Lost Sales
- \(USL\) = Unit Cost for Lost Sales
- \(X_{RIQ}\) = Coefficient for Recoverable Inventory Quantity
- \(RIQ\) = Recoverable Inventory Quantity
- \(X_{SIQ}\) = Coefficient for Serviceable Inventory Quantity
- \(SIQ\) = Serviceable Inventory Quantity
- \(X_{RHC}\) = Coefficient for recoverable holding Cost per item
- \(RHC\) = Recoverable holding Cost per item
- \(X_{SHC}\) = Coefficient for serviceable holding Cost per item
- \(SHC\) = Serviceable holding Cost per item

The following data has been obtained from a firm doing remanufacturing based in Pune, India. All values here represent Indian Rupee. Based on the above data linear programming has been done, a minimized value of cost...
has been found. The minimized inventory cost for one month has been found to be 355000 Rupees.

**SIMULATION**

Simulation is the imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviors of a selected physical or abstract system. Simulation had been done for the model created. Simulation has been performed using ARENA simulation software. The results obtained have been discussed here.

A screen shot of the ARENA simulation software is shown above. Here the variation inventory levels with time are shown. It has been found that fluctuations are higher at the start, however they even out as time passes. Simulation has been performed for residence time of 2 years and 4 years.

In the image the Demand, Production and sales for a residence time of 2 years have been shown. From the image it can be seen that, the remanufacturing in the reverse logistics is much lower than the demand. It is understood that remanufacturing alone cannot satisfy the demand for the current return index. Hence remanufacturing along with production is done in order to ensure that demand is met.
Here the holding cost and the average shortage cost is shown, it can be seen that the holding cost is much lesser than the shortage cost, this indicates that there is a shortage in returns. An increase in the return index will offset thus problem. The average ordering cost and the average total cost has also been obtained. These values concur with the values obtained from the company; hence the model has been verified.

CONCLUSION

Inventory control is a fundamental activity in closed loop supply chains, particularly for remanufacturing processes. Using causal loop diagram (CLD) and stock and flow diagram (SFD), the paper provides an understanding of the inventory control system structure as it identifies the important factors or variables influencing the system as well as the causal influence among these variables. The paper generates a mathematical model for minimizing the inventory cost by increasing the returns. This is done by controlling the return index by introducing two factors namely Customer behavior and service agreement with the customer. Finally the model is validated with a set of realistic data from a remanufacturing company.

REFERENCES


