Remanufacturing in Reverse Supply Chain Management

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ABSTRACT---- ***Increasing pressure to improve market competitiveness has pushed companies to consider the reverse supply chain because of economic and environmental benefits. Besides, legislations and directives, consumer awareness and social responsibilities towards environment are also the drivers for reverse supply chain. The process of reverse supply chains are more complicated since return flows may include several activities such as collection, checking, sorting, disassembly, remanufacturing, disposal and redistribution. Moreover, the quality and the quantity of the used products are uncertain in the reverse channel. The complexity of reverse supply chain has motivated several researchers to use System dynamics (SD) modelling techniques in the search for better strategies and policies for integrating the forward and reverse supply chains by addressing the effects of uncontrollable factors such as uncertainty of returns. The paper aims at not only proposing a methodology that provides an understanding of the system structure as it identifies the important factors or variables influencing the system and to study the characteristics of the process but also it highlights the measurement and improvement of the reverse supply chain.***

Keywords--- Reverse supply chain, System dynamics, Complexity, Measurement, Time reduction.

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1. INTRODUCTION

Reverse supply chain has been an area of increasing importance recently. Reverse supply chain is concerned with the transfer of materials in a direction opposite to that of the traditional supply chain ie the transfer of materials from the consumers to the suppliers[2]. Recovery of used products is the answer to the depleting resources and decreasing disposal facilities. Although several methodology have been developed for RSC, but none have been standardized. For recovery of used products there are five main options [3]. They are reuse, recycle, remanufacturing, refurbishing and repair. In this paper recovery of products through remanufacturing is considered. Reuse refers to the activities that reuse products without any repairing. The examples are bottles, cans, mosquito repellent refills etc. Repair refers to the activities that bring used products to working order. Eg are domestic appliances, industrial machines etc. Remanufacturing refers to getting the used product to as good as new conditions. Cell phones, laptops are good remanufacturing options. Recycling is the material recovery of used products without maintaining their structures. Paper, plastic are good examples for remanufacturing. System Dynamics [4] is a methodology for the study of complex systems with time. 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. 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.

2. LITERATURE REVIEW

The phenomenon of reverse logistics is ancient, and it will not wither away either in the future. In the last few years, accompanied with the intensification of logistics, more and more enterprises have started to realize the importance of reverse logistics management. The concept of reverse logistics is gaining significant attention from within the realms of academia and industry. Reverse logistics has been used in many industries like photocopiers (Krikke, van Harten, & Schuur, 1999; van der Laan, Dekker, & Van Wassenhove, 1999) single- use cameras (Toktay, Wein, & Stefanos, 2000), jet engine components (Guide & Srivastava, 1998), cellular telephones (Jayaraman, Guide, &Srivastava, 1999), and refillable containers (Kelle & Silver,1989).The computer hardware industry has already begun to embrace reverse logistics by taking steps to streamline the way they deploy old systems; and in the process make it easier for the customers to refurbish existing computers or buy new parts (Ferguson, 2000). System Dynamics (SD) (Forrester 1958, 1961), a methodology for studying and managing complex feedback systems, more particularly business and social systems, to model a remanufacturing system in which production is integrated with remanufacturing processes in order to analyse the effects of external factors on returns rate. Returns rate is one of the main reverse logistics factors affected by uncertainty in timing and quantity of returns (Guide 2000). A System Dynamics simulation tool was developed to analyse the dynamic behaviour and the influence of the various activities on the reverse logistics network (Georgiadis & Vlachos 2004a). 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. In another similar study using System Dynamics (Georgiadis & Vlachos 2004b), the impact of environmental influences and remanufacturing capacity planning policies were simulated on the behaviour of a reverse logistics system. They analysed 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. A remanufacturing system was modeled using SD to study the impact of product lifecycles on planning optimal collection and remanufacturing capacities for several kinds of products with different lifecycles and return characteristics (Georgiadis, Vlachos & Tagaras 2006).

3. 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. 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. 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.

In order to control the returns the obvious solution is to control the return index because from the sensitivity analysis it has been seen that return index is the most influential factors among the factors affecting the returns. 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

4. 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 (Coyle 1996). 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 (Sterman 2000).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 (Sterman 2000).

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. Coyle (1996) states that while the causal loop diagram represents a real system through variables connected by signed links, a quantitative model represents the same system using variables in equations.

Before starting the simulation of the model, validation and verification processes must be performed. The validity for a System Dynamics model defines its capacity to reflect the structure and behavior of a real process model. Linear programming test is being used in this inventory control, so that, we can find the optimal and minimal inventory cost. These tests utilize several comparisons including the form of the equations, conceptual or numerical value for model parameters, value of the output variable applying extreme conditions values to the input variables of the equations and finally, dimensional consistency for both side of each equation.

4.1 CAUSAL LOOP DIAGRAM ALONG WITH NEW FACTORS

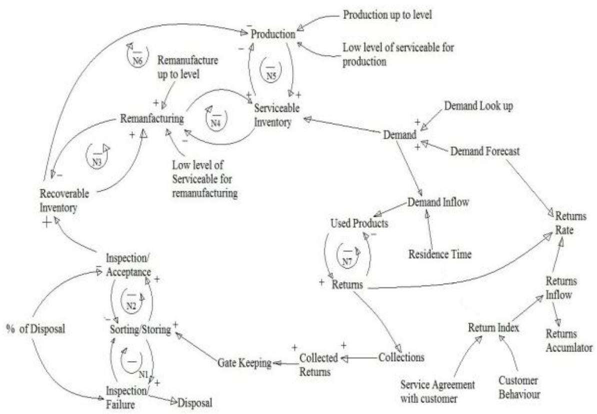

Figure 1: Causal loop diagram for inventory control

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.

4.2 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.

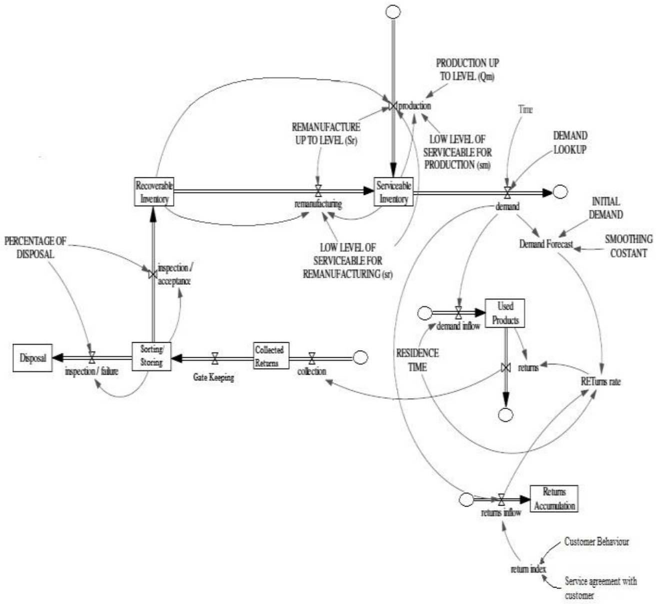

Figure 2: Stock and flow diagram for inventory control

4.3 MATHEMATICAL FORMULATION

The dynamic behavior of the remanufacturing system is implemented by a set of mathematical equations that has been obtained from the stock an d 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) = demand (t) * return index (t)*

The returns rate depends on the returns inflow and demand.

- *Returns Rate (t) = returns inflow (t) / demand (t)*

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

- *Returns (Tx) = Used Products (t) * Returns Rate (t) / RETURN TIME*

Demand inflow is obtained using a delay fixed function

- *Demand inflow = DELAY FIXED (demand, residence time, 0)*
- *Used Product = ∫ [returns (t) – demand inflow (t)]*
- *Demand (t) = 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 ((serviceable inventory=< low level of serviceable for production) && (Recoverable inventory <= (low level of serviceable for remanufacturing + Remanufacturing up to level)))*
    - *Production = production upto level- serviceable inventory*

Else

- *Production = 0*

- *If ((serviceable inventory=< low level of serviceable for production) && (Recoverable inventory >= (low level of serviceable for remanufacturing + Remanufacturing up to level)))*
    - *Remanufacture = Remanufacturing upto level- Low level of serviceable for Remanufacturing*

Else

- *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) =∫ inspection/acceptance (t) – remanufacturing*
- *Serviceable inventory (t) = ∫ Remanufacturing (t) + Production (t) – Demand (t)*
- *Sorting/Storing (t) = ∫ Gatekeeping (t) – Inspection/Failure (t) – Inspection/Acceptance (t)*

- *Collected Returns = ∫ Collection (t) – 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.

- *Inspection / Acceptance (t) = Sorting / Storing * (1- Percentage of disposal)*
- *Inspection / Failure (t) = Sorting / Storing * (Percentage of disposal)*

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

- *Percentage of remanufacturing* $= 1 / (1 + e^{m})$
- $M = a_2 (C_{Remanufacture} - C_{Disposal}) / C_{Production}$

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

- *Returns (t) = 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 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*

4.4 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.

$$MIN\ (Z) = X_{FS} + X_{NFS} + X_{LS} + X_{U.S.L} + X_{RIQ} + X_{SIQ} + X_{RHC} + X_{SHC}$$

Subjected to,

1) $FS*X_{FS} + NFS*X_{NFS} <= SC$
2) $LS*X_{LS} + USL*X_{USL} <= SO$
3) $RIQ*X_{RIQ} + SIQ*X_{SIQ} + RHC*X_{RHC} + SHC*X_{SHC} <= HC$

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.

Table 1: Data obtained from a firm

Fixed Setup Costs per reorder	Rs10000
Unit cost for lost Sale	Rs 25000
Recoverable inventory holding cost per item	Rs 3
Serviceable inventory holding cost per item	Rs 6

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.

5. 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.

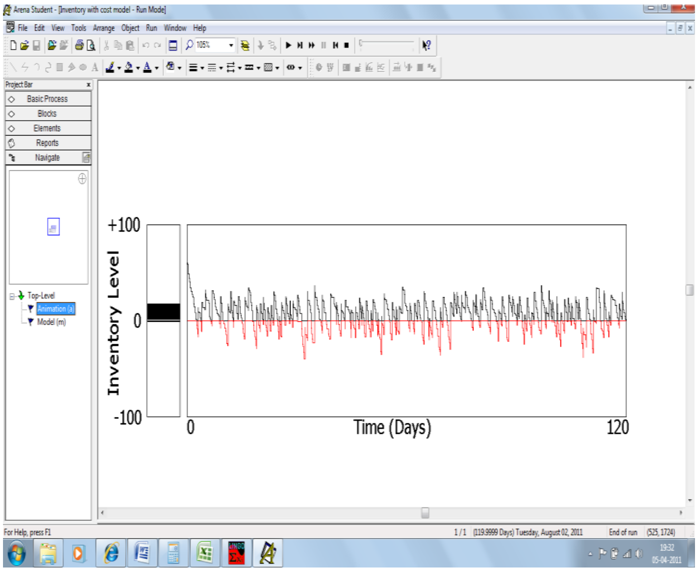

Fig 3: INVENTORY FLUCTUATIONS OVER TIME

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.

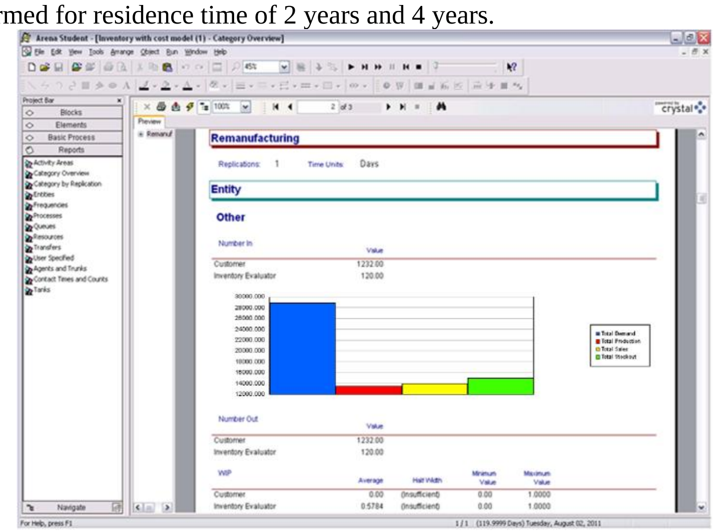

Fig 4: Arena output 1

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.

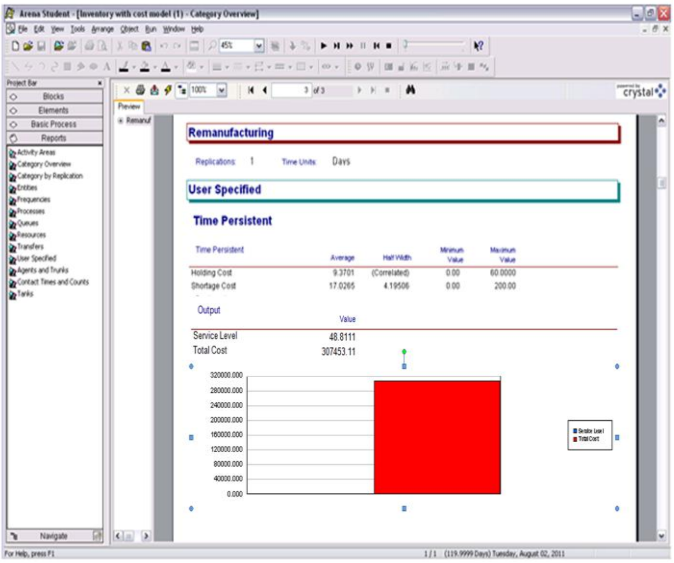

Fig 5: Arena simulation output 2

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.

Inventory control

Inventory of any individual original equipment electronic manufacturer consists of hundred and thousand of varying costs, usage and lead time for collection from various wards. Easy method has to be formulated to exercise control over these products or parts. It is neither desirable nor possible to exercise same degree of control over all the items. Items should be ranked with the first sale usage and first sale price. This inventory is called as selective inventory. Selective inventory is a dynamic procedure for the inventory control. It helps in exercising selective control over the items by concentrating efforts in areas where it needed most. For instance, control over 'C' items may be relaxed even to the extent of dispensing with inventory records. For 'A' items the buffer stocks must be kept the absolute minimum and very careful attention is paid to their demand estimates, scheduling and inspection. It avoids wastage of time and energy in making improvements in areas that yield only marginal benefits.

Inventory can be categorized into three major types if the product or parts are found to be recoverable. Selective inventory can be adapted to the recoverable parts or product. Three categorized inventory are most preferred, proportionately preferred and less preferred. Preference rating is based on the first sales of the product. It fetches more profit to the original equipment manufacturer to control inventory based on the selective inventory control, as preferred products are treated with high demand based on products price tag and usage value. For the selective inventory control it is assumed that products has the highest first sale price tag and usage is the most preferred in remanufacturing market. General steps for the selective inventory control is listed below

- Find the annual usage value of every item in the sample by multiplying the annual requirement by its unit cost.
- Arrange these items in descending order of the usage value computed above.
- Accumulate the total number of items and the usage value.
- Convert the accumulated totals of number of items and usage values into percentage of the grand totals.
- Plot the two percentages on the graph.
- Mark the cut off points X and Y where the curve changes its slope, dividing it into three segments A,B and C.

These segments A, B and C for the sample are the generalized over the entire population of stock items.

In selective inventory analysis, an organization would devote much time and effort in the control of 'A' items. Extra care will be taken for determining the minimum, maximum inventory levels and reorder level etc. of the 'A' items whereas so much control may not be exercised on 'C' items.

First step is to compute the annual usage for each item by multiplying the per unit price by annual the annual use and to rank them in descending order of their annual usage values.

Table 2:

Model number	Annual consumption in pieces	Unit price in Rs	Annual usage value in Rs	Ranking
M1	10000	7500	75000000	4
M2	5040	10000	50400000	5
M3	49632	9500	471504000	1
M4	4923	7600	37414800	7
M5	7835	5000	39175000	6
M6	6120	2100	12852000	8
M7	2300	1300	2990000	10
M8	35023	12000	420276000	2
M9	21003	10000	210030000	3
M10	1300	3050	3965000	9

Next step is to accumulate the total number of items and their usage value and then to convert the accumulated values into the percentages of the grand totals.

Table 3:

Model Number	Category	Annual usage in Rs	Cumulative annual usage in Rs	Cumulative annual usage percentage	Percentage of model
M3	**A**	471504000	471504000	35.6	10
M8		420276000	891780000	67.3	20
M9		210030000	1101810000	83.2	30
M1	**B**	75000000	1176810000	88.9	40
M2		50400000	1227210000	92.7	50
M5		39175000	1266385000	95.6	60
M4		37414800	1303799800	98.5	70
M6		12852000	1316651800	99.4	80
M10	**C**	3965000	1320616800	99.7	90
M7		2990000	1323606800	100	100

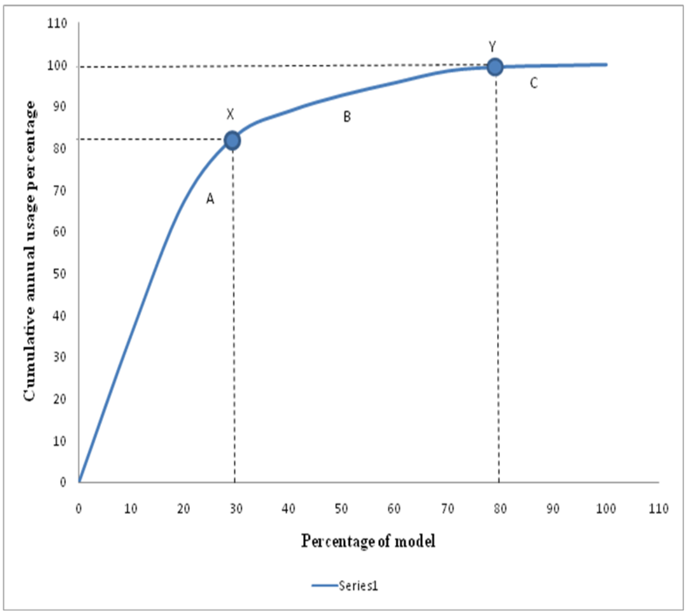

Fig 6:

Mark the cutoff points X and Y where the curve changes its shape this divides the curve into three segments A, B and C. From the graph it is clear that it is necessary to control only 30% of the inventory item to achieve tight control over 83%

total annual value of inventories. On the other hand 20% of the items can be virtually ignored and still there will be loss of control over only 1% of the total annual value.

6. CONCLUSION

The paper aims at not only proposing a methodology that provides an understanding of the system structure as it identifies the important factors or variables influencing the system and to study the characteristics of the process but also it highlights the measurement and improvement of the reverse supply chain.

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