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Methodology for Study of Characteristics and Time Reduction in Reverse Supply Chain Using System Dynamics

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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, environmental benefits.

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. Remanufacturing refers to getting the used product to as good as new conditions. Cell phones, laptops are good remanufacturing options.

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).

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 analyze 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 analyze the dynamic behavior 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. It was found that total costs decreases when higher remanufacturing capacities are reached.

3. Methodology

The methodology used here flows from the causal loop diagram through the stock and flow diagram and onto the time measurement and based on the results, improvements are proposed and results are drawn.

4. Causal Loop Diagram

A causal loop diagram (CLD) provides an understanding of the system structure as it identifies the important factors or variables influencing a system as well as the causal influence among these variables. A CLD consists of variables connected by arrows. The behavior of the system is defined by seven negative feedback loops [1] labelled 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 amount of acceptance is inversely proportional to the percentage of disposal.

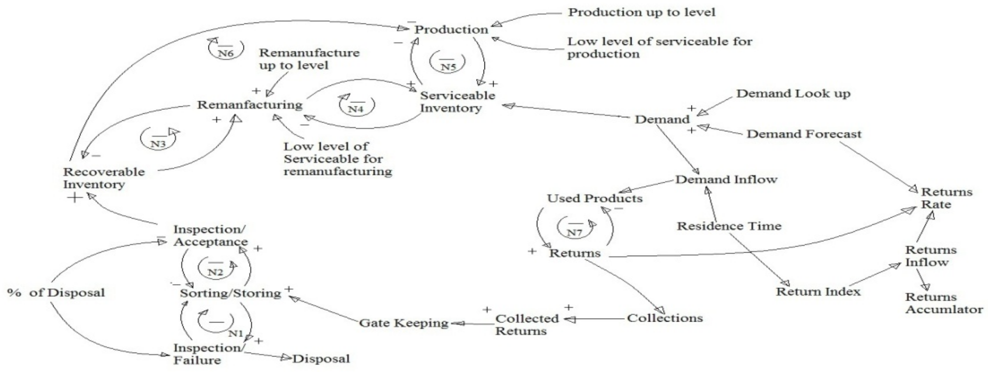

Figure 2: Causal Loop Diagram

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 the residence time, is used to set the number of possible returns from the customer demand. This is represented by the returns inflow which is influenced by the returns index and demand. In order to set the number of returns from used products a returns rate is used which is generated through the relationship with possible future Demand Forecasts and possible returns from demand. Finally, product lifetime is not related to any of the variables in the system but it is shown as it gives a better interpretation of the variable return index.

5. Stock Flow Diagram

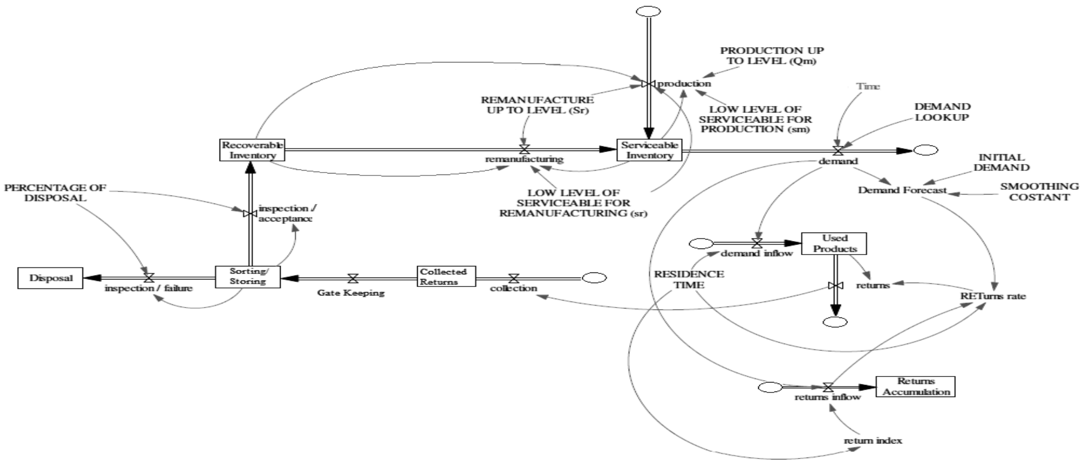

Figure 3: Stock Flow Diagram

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 [5]. Through the SFD, it is possible to analyse 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, Returns accumulations. Flow variables are percentage of disposal, inspection/failure, inspection/acceptance, collection, gate keeping, Remanufacture upto level, low level of serviceable for remanufacturing, production upto 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.

6. Measurement

The relevant supply chain actors in the supply chain are identified. These may include Forward Supply chain actors, facilitators and reverse supply chain actors. Form closed loop network structure that takes the worst case scenario of the project and information flow. The Reverse Supply Chain entry and exit points are identified. The earliest RSC_{entry} and the last RSC_{exit} points should be identified. The activities between the entry and the exit of the reverse supply chain are noted. First the various operations involved should be identified and then the activities involved in each of these operations should be identified. A process flow chart is developed and the observed time is noted. Now, from the observed time the standard time is noted. Identify the possible activities that can be classified in the value recovery category. Now the standard time for the various process in the flow chart are noted. Then the ST for the RSC operations is noted. The initial time parameters from which the final time parameter is to be found is calculated.

Total time taken for RTU_1 to traverse the RSC

$TT_{RTU1} = \sum(ST_{RSC1}+ST_{RSC2}+.......+ST_{RSCn}+STVR_{RSC1}+ STVR_{RSC2}....... +STVR_{RSCn})$……………………*Eq 1*

Value Recovery Time of RTU1

$VRT_{RTU1} = \sum(STVR_{RSC1} + STVR_{RSC2} +....+ STVR_{RSCn})$…*Eq 2*

Similarly calculate VRT_{RTU2} VRT_{RTU3} VRT_{RTU4} ……… VRT_{RTUn}

Calculate the following "final" time parameters:

(i) Average Total Time (Avg. TT): This is the average of TT of all RTUs for the given time period under consideration.

(ii) Average Value Recovery Time (Avg. VRT): This is the average of the VRTs of the various RTUs in the same time period.

(iii) Time Efficiency (T.E): This parameter is similar to the concept of Lean ratio in the FSC that is given by dividing VAT by the total time taken. This is given by the following formula

T.E = Avg. VRT / Avg. TT…………………………*Eq 3*

(iv) Non-Value Recovery Time (NVRT): This is the total time that is spent on all activities excluding the VRT. Hence it is given by the following equation.

NVRT = Avg. TT – Avg. VRT..……………………*Eq 4*

(v)Average Standard Time of process categories (Avg. STi): For each of the various process categories listed in the process flow chart, we calculate the average standard time using the following equation.

Avg. ST of a given process category i = Total ST of the process category / no. of RTUs under consideration under the given time period……………………………………*Eq 5*

6.1. Case Study

A time measurement study has been conducted for a reprocessing company based in Bangalore, India. From the data that has been obtained the standard time and the value recovery time for each process has been identified. The following table has been prepared, for data collected from an Indian reprocessing firm in Bangalore.

Process	RTU1		RTU2		RTU3		RTU4		RTU5	
	ST	STVR	ST	STVR	ST	STVR	ST	STVR	ST	STVR
Gatekeeping	34	6	30	5	39	9	30	10	40	7
Sorting/Storing	10	0	12	0	15	0	13	0	17	0
Inspection	12	0	15	0	10	0	15	0	18	0
Recoverable inventory	4420	1680	4350	1690	3900	1620	4030	1630	3850	1620
Remanufacturing	110	60	140	80	150	80	120	65	135	65
Total Values	4586	1746	4547	1775	4114	1709	4208	1705	4060	1692

Table 1: ST and STVR for the various processes.

From the data collected, the average standard time for each process has been recorded.

Process	Avg Time
Gatekeeping	34
Sorting/Storing	13
Inspection	14
Recoverable inventory	4110
Remanufacturing	131

Table 2: Avg ST for the various processes.

The plots for various processes and their STs, and that of other parameters have been shown here.

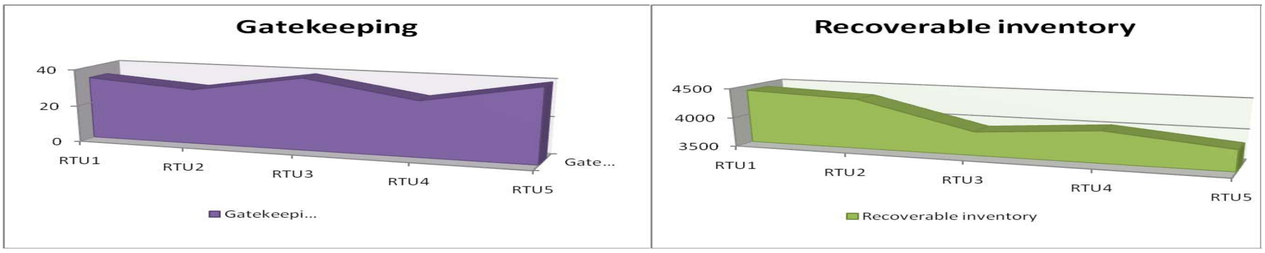

Figure 4: Avg ST for Gate keeping VS RTUs and Avg ST for Recoverable Inventory VS RTUs

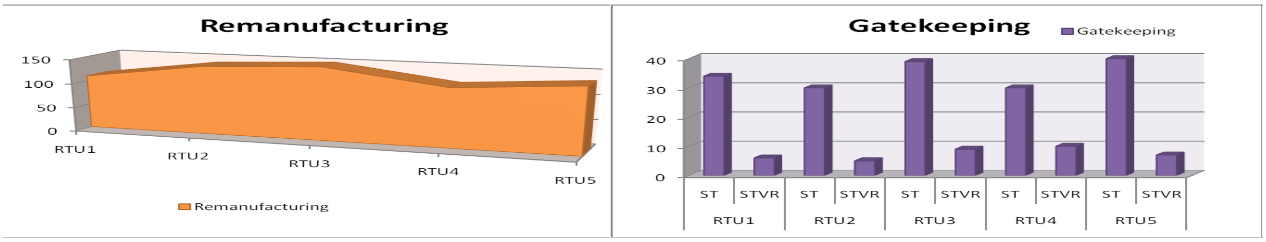

Figure 5: Avg ST for Remanfacturing VS RTUs and ST and VRT VS RTUs in Gatekeeping

Figure 7: Activities VS Avg Time

For the Data obtained the time efficiency can de calculated through the following procedure.

Total Standard time of RTU1= $ST_{Gatekeeping} + ST_{Sorting/Storing} + ST_{Inspection} + ST_{Recoverable\ inventory} + ST_{Remanufacturing}$

Total Standard time of RTU1 = 34+10+12+4420+110

= 4586 minutes

Total Standard time for Value Recover of RTU1= $ST_{Gatekeeping} + ST_{Sorting/Storing} + ST_{Inspection} + ST_{Recoverable\ inventory} + ST_{Remanufacturing}$

Total Standard time for Value Recover of RTU1= 6 + 0 + 0 + 1680 + 60

= 1746 minutes

Similarly the Total Standard time and value recovery time is found out for RTU 2 to 5.

Average Total time = $(ST_{RTU1} + ST_{RTU2} + ST_{RTU3} + ST_{RTU4} + ST_{RTU5}) / 5$

= (4586+4547 +4114 + 4208 + 4060)/ 5

= 4303 minutes

Average Value Recovery Time = $ST_{VRT1} + ST_{VRT2} + ST_{VRT3} + ST_{VRT4} + ST_{VRT5}$

= (1746 + 1775 + 1709 +1705 +1692)/5

= 1725 minutes

Average Non Value Recover time = Average Total Time – Average Value Recovery time.

= 2578 minutes

Time Efficiency = Average Value Recovery Time / Average Total time

= **40.1 %**

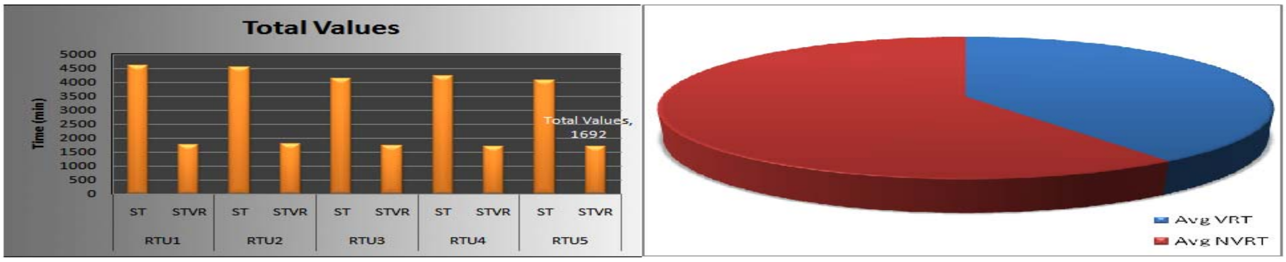

Figure 8: ST and STVR VS RTUs and Avg VRT vs Avg NVRT

The time efficiency has been found out and it can be seen that it is low. This offers plenty of scope for improvement.

6.2. Improvement

- A spider diagram that shows the current state of the parameters and the projected target can be developed for each of the parameters. After the target is set pareto analysis is done to focus on the improvement initiatives. This is followed by a root analysis.
- Return reasons should be checked at the gate keeping site. This helps in easier recovery as the return reasons are classified and coded.
- Central pool of database that lists all RTUs: Often times, it is always advantageous to have an integrated database that lists all the available RTUs across different units of the same organization. While designing a product it should be designed by keeping the disposal or the recovery of the product after its use.
- A Clear demarcation between the FSC and RSC products should be maintained to avoid confusions.

7. Conclusion

Using causal loop diagram (CLD) and stock and flow diagram (SFD) the paper provides an understanding of the system structure as it identifies the important factors or variables influencing a system as well as the causal influence among these variables. It also provides a possibility to analyze the dynamic characteristics between rate and level variables and define the relationships among the variables of the model. The second part of the paper proposes a method for measuring time by considering the number of stages in reverse supply chain and after careful analysis improvements has been proposed to reduce the overall time taken for RSC operations.

8. References

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