System Dynamics Modelling for Reverse Logistics Supply Firm

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Abstract

Reverse supply chain is becoming very important in recent time. The objective of this study is to understand the causal modelling of the flows in reverse supply chain with help of a case. The various policy interventions have been modelled thereby providing managerial insights into the policy implications for the company. The methodology used in this research is System Dynamics Modelling. The research uses causal loop diagram to identify the reinforcing and balancing loops then develops a system dynamics model to test the implications of the various policy measures. After policy implementation the As-it-is stock which can generate more revenue through higher prices is increased and the refub stock and cannibalised stock is decreased. Thus the policy changes have a positive impact on the revenue.

Key Words: Reverse logistics, Causal modelling, Remanufacturing, System Dynamics

Introduction

Supply chain has movement of product downstream from the producer to the consumer and upstream from consumer to the producer. The upstream movement of the product may be due to many reasons including defects, returned sell etc. The activities associated with upstream movement of the product after it is sold is called reverse supply chain. The main differences between Forward and Reverse Supply Chain include one to many transportations in forward whereas many to one in the case of reverse. The product quality is not uniform for reverse and also the routing is unpredictable and unknown. (Tibben-Lembke & Rogers, 2002)

Several factors that motivate manufacturers to engage in product recovery: reducing production cost, enhancing brand image, meeting customer's demand, protecting aftermarkets and pre-empting regulations (Toffel, 2004). The products may be returned at different stages in the product lifecycle and based on this it would take different paths.

Literature Review

With the changing times and growing, regulation firms are also required to take responsibility for the end-of-life collection and recycling of their products. The possible options for dealing with EOL products include keeping the product and storing it temporarily, disposing of the product via landfills or recycling the product (Knemeyer, Ponzurick, &logar, 2002). However, land being a scarce resource the capacity of landfills is also declining with time. The conversation of environmental sustainability has forced companies to review their supply chains by examining their carbon footprints and energy usage and being socially responsible for the complete lifecycle of their product. This has given rise to the concept of reverse logistics which is defined as "the process of moving goods from their typical final destination for the purpose of recapturing value or proper disposal" (Genchev, 2009). The regulations have had an impact on both the customers and the manufacturers. While the manufacturers are making products which are easy for disassembly, reuse and remanufacturing owing to environmental regulations, the number of customers supporting environmental protection is also increasing and the increase in the collection of reused products is indicative of the same (Lee & Chan, 2009).

There are certain similarities and differences in the forward and reverse logistics chains. The differences can be understood in terms of the quantity, category, cycle time, stock keeping units and distribution paths. The products traversing the reverse chain are usually small in quantity, have different types, have an uncertain cycle time for collection Thus the greatest challenge in the reverse logistics is the uncertainty in the return timings, quantity and the quality of the products returned by the customers (Fleischmann, Bloemhof, Dekker, Van Der Laan, Van Nunen, & Van wassenhove, 1997). Each return may, therefore, require specific treatment depending on the defective, damaged, recyclable or repackageable nature of the item received. The flow of the reverse chain, therefore, involves collection, sorting, storage, transportation, inspection,and reduction. The commonality is the aim of reducing in-transit inventory carrying costs in the complete cycle (Lee & Chan, 2009). In spite of this, companies often fail to distinguish the two and try to incorporate the reverse logistics within their forward logistics operations (Knemeyer, Ponzurick, &logar, 2002). The total value of reverse logistics was about 4% of all the logistics cost in 1997. It is a fact that the total processing cost of returned products is higher than their manufacturing cost. Developing reverse logistics services should, therefore, be viewed as an effective means of nurturing a competitive advantage (Stock, Speh, & Shear, 2002). Effective collection of the returned products can lead to repetitive purchases and reduces the risk of fluctuating demand and cost (Lee & Chan, 2009). Bellman and Khare (1999, 2000) created the concept of having a minimum quantity called "critical mass" for the viability of reverse logistics business. It also emphasis on considering the issues of post usage considerations like collection, segregation and recycling and remanufacturing in the design phase itself.

Meade and Sarkis (2002) suggests at bringing in efficiency in the forward and reverse logistics collectively looking at reverse logistics network. Sun and Rong (2013) looked at the high returns in retail due to defective products while Ni and Zha (2011) looked at information asymmetry. The influence of quality policies was studied and its implication across the reverse logistics chain(Wassenhove and Zikopoulos (2010); Zikopoulos and Tagaras, 2007). It was found that the delivery costs are in line with the product of goods quantity, quality and transportation distances (Yang et al. 2013).Xanthopoulos et al. (2012) focused on creating guidelines for reverse logistics mechanisms for efficient product take-back, and reuse and recycling of specific components and materials of end-of-life buildings. Mutungi (2014) focused on simulation for reverse logistics from green perspectives. Sudarto et.al, (2017) studied the uncertainties in these reverse logistics chains and how to bring efficiency by considering product life cycle.

This study uses a Green Dust as case organization for system dynamics modelling. It is a logistic company from India dedicated in managing reverse logistic. The objective of this study to understand the GreenDust's supply chain using causal diagram. The paper develops a stock and flow system dynamics model to understand the baseline behavior of the model. The study further analyses the effect of policy intervention on the system.

Methodolgy

This section describes the steps of model development for the operation of the organization under the study. The system was defined such that it is neither too simple to address the complexity nor too complex to handle. The method used in this research is computer simulation method known as System Dynamics. The simulation is a method that allows experiment on the system through a computer-based model of the system (Yih, 2010; Forrester, 1994; Homer et al., 2004).

The literature suggests that system dynamics model has unique ability to mimic the real world scenario. This research uses system dynamics (SD) model because it is simple, powerful, useful and natural for addressing the dynamic complexity of social welfare supply chain.

The SD approach is based on control theory, and it postulates that system behavior is caused by system structure. The hypothesis is driven by the insight the modeler has about the system behavior. Without intelligent guess about the operation of the system, an SD model is futile or at least extremely laborious. The various types of variables used in SD model are:

Stocks: A stock is a term for any entity that accumulates or depletes over time.

Flows: A flow is the rate of change of the stock.

Auxiliary Variables: Variable which changes the flow or combines with another auxiliary variable to produce auxiliary variable.

The steps involved in system dynamics modelling are as follows:

Determining the modelling goals: Deciding upon the behavior we want to analyze using the model

Defining the system: Identifying the component of the system i.e. stocks, flow and auxiliary variables

Development of Causal Loop Diagram: Causal loop diagram helps us in identifying the reinforcing and balancing loops

Developing Stock and Flow Diagram: Developing Stock and Flow Diagram using Vensim System Dynamics tool

Initialization of Model: Using the parameter data to initialize the stock values

Estimation of Auxiliary Variable: Estimation of auxiliary variable using the secondary research and inputs from focus group discussions

Simulating the Model: Simulating the model to analyze the Baseline behavior and effect of policy interventions

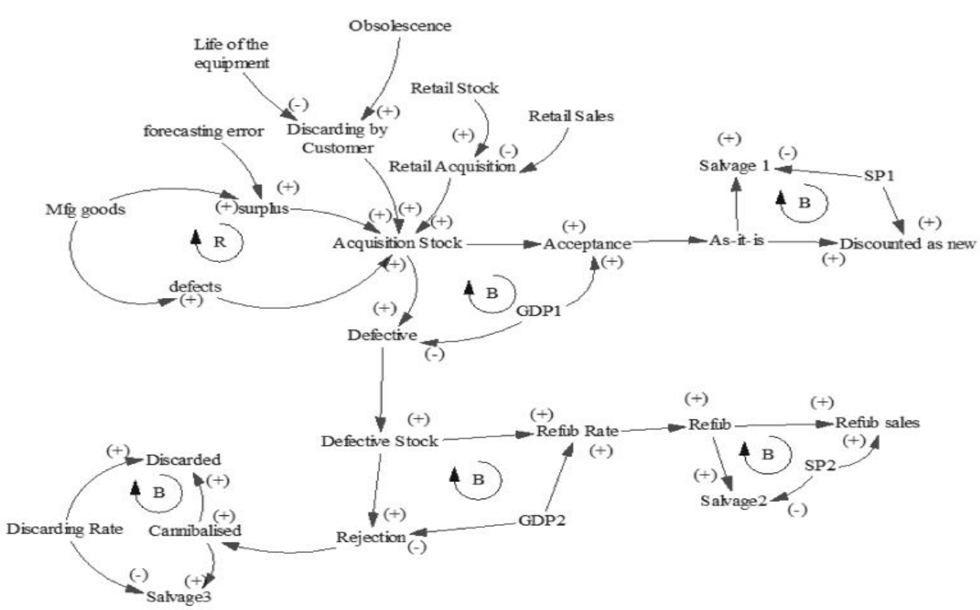
Causal Loop for the System Dynamics Model:

Causal loop diagrams (CLD) are an important tool for representing the feedback structure of the system. A CLD consist of variables connected by arrows denoting the causal influences among the variable, which helps in identifying the important feedback loops in the diagram. The variables are related by causal link, shown by arrows. The figure below depicts the causal loop diagram for the model.

Modelling the Causal Loop for GreenDust:

Green Dust sells quality product at discounted price with warranty and after-sales services. It mostly sells refurbished product and factory seconds which are as good as original product in functional use. The Figure 1 depicts the causal loop diagram (CLD) of the supply chain of GreenDust. The diagram contains one reinforcing loop represented by letter R while five balancing loops represented by letter B. Behind every growth or decay is at least one reinforcing loop. For every goal-seeking behavior, there is a balancing loop. The presence of reinforcing loop can result in exponential growth and decay. The presence of the balancing loop ensures that there is not an exponential growth or decay. The balancing loop involving Acquisition Stock, As-it-is, Defective stock, and Refub item ensures that there is not an exponential increase in the stock for these items.

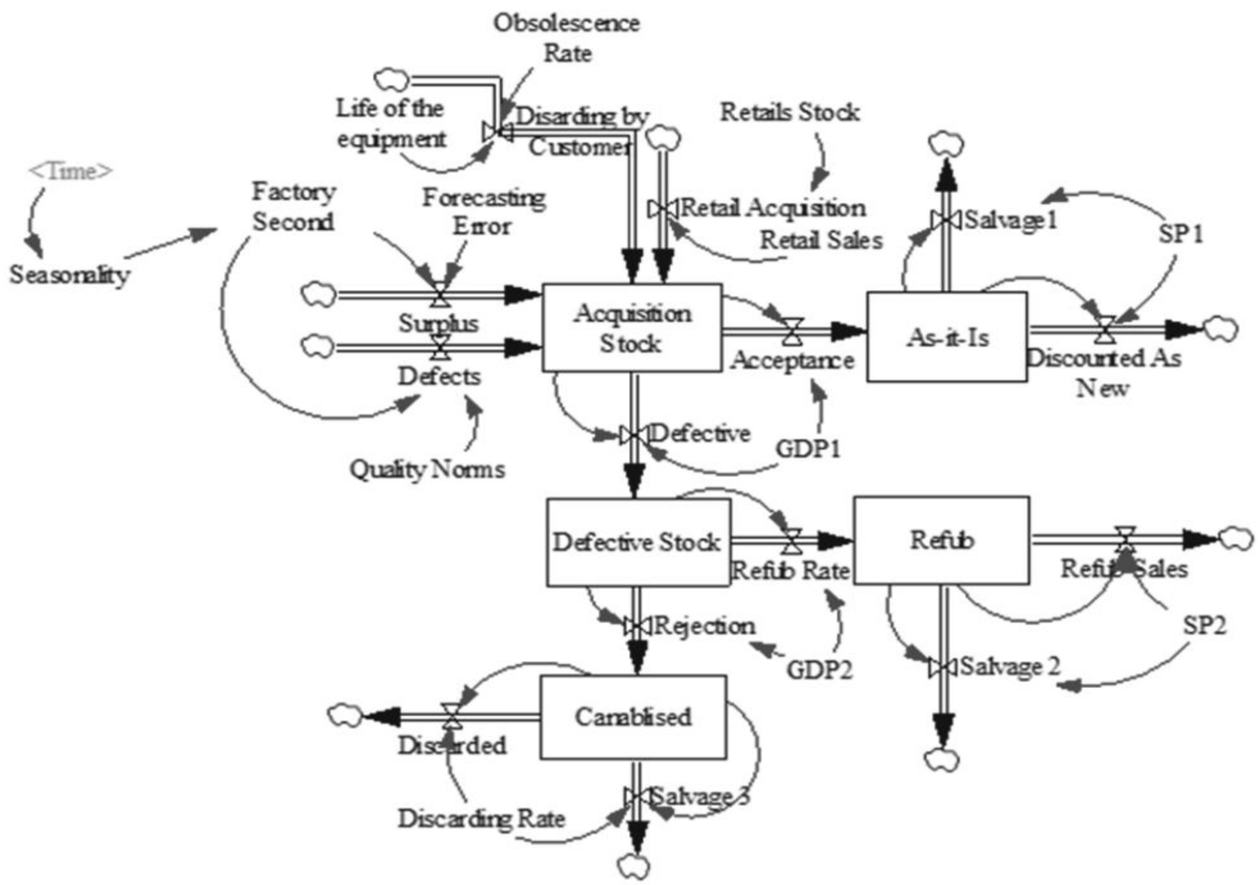
Figure1: Causal Loop Diagram for Green Dust Supply Chain



Stock and Flow Diagram

Stock and flow diagrams provide a better visual depiction than causal loop diagrams. The figure 2 below provides stock and flow diagram (SFD) for the GreenDust supply chain. It also helps us in understanding the mathematical relationship between various stock, flow, auxiliary variables. GreenDust policy for accepting a stock for As-it-is sales is denoted by GDP1 (GreenDust Policy 1) in the stock and flow diagram. Similarly, the policy related to selling a product as refurbished or cannibalising the product is denoted by GDP2(Green Dust Policy 2). Sales percentage for As-it-is sales and refurbished sales is represented by SP1 and SP2 respectively in the SFD.

Figure 2: Stock and Flow Diagram for Green Dust Supply Chain



Initialization of the Model:

For initialization of stock and estimating the value of the auxiliary variable used in the stock and flow diagram the study uses secondary research and in-depth interview of the management at the organization under study. The initial value of the stock variable is as follows:

[Acquisition Stock: 5000; Defective stock:2000; Cannibalised:800; As-it-is-3000; Refub-1200; Retail Stock-10000; Obsolescence rate-10000]. The model was simulated for initial values to understand the baseline behavior. Once the model is analyzed for the baseline behavior (the behavior with the initial values) a policy measure was implemented to affect the auxiliary variable in desired direction. It was assumed that the policy will help in increasing quality norms, green dust policy (GDP1 and GDP2) and Sales Percentage (As-it-is and Refurbished Sales) and will decrease the discarding rate. The value of retail system is independent of policy measures and hence the value of the 'Retail Sales' doesn't change after policy implementation. The Initial and Targeted Value for the different auxiliary variable areQuality Norms (0.6 to 0.8); Discarding rate (0.8 to 0.6); Green Dust Policy 1 -GDP1 (0.6 to 0.8) Green Dust Policy 1-GDP1(0.6 to 0.8); Sales Percentage 1 -SP1(0.4 -0.6); Life of Equipment (0.5-0.5) and Retail Sales (0.7-0.7)

Results & Discussions

Figure 3: Effect of Policy Implementation on As-it-is Stock

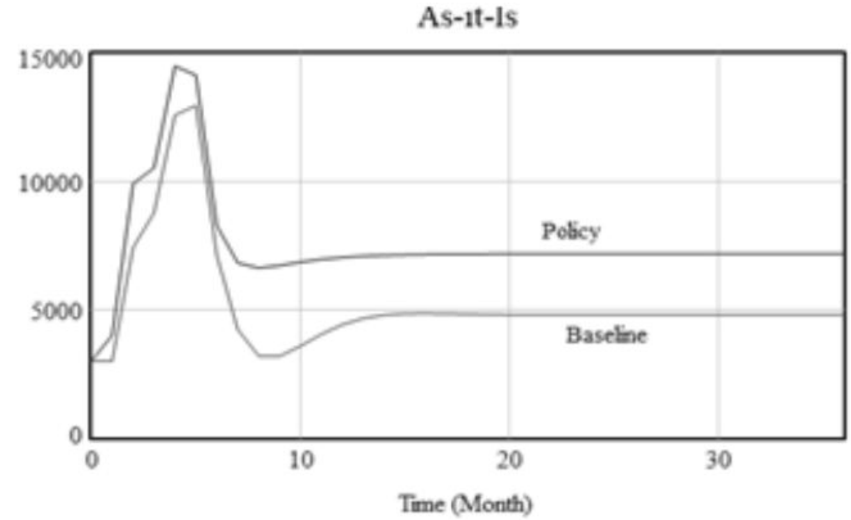


Figure 4: Effect of Policy Implementation on Refub Stock

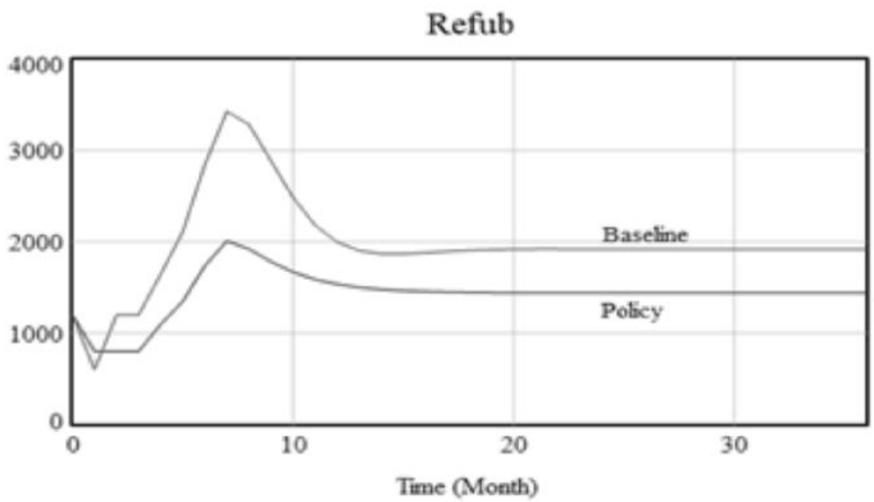
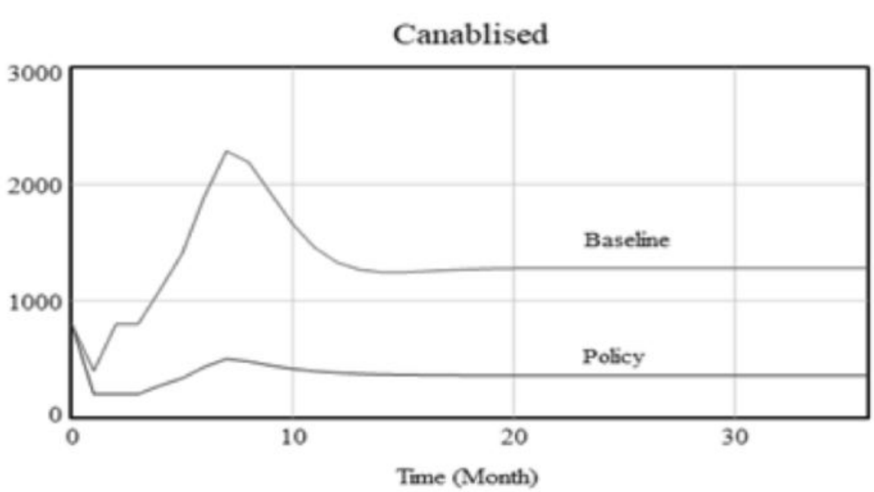


Figure 5: Effect of Policy Implementation on Cannibalised Stock



As can be seen from Fig.3, Fig.4 and Fig.5 collectively, after policy implementation the As-it-is stock which can generate more revenue through higher prices is increased and the refub stock and cannibalised stock is decreased. Thus the policy changes have a positive impact on the revenue. Next, the study examines the effect of increasing the life of the equipment on the system. The life of equipment is denoted by a multiplier in the system and its value was increased by 60% from 0.5 to 0.8. The figure 6-8 depicts the effect of increasing the life span on the stock variables being studied by delaying the obsolescence.

Figure 6: Effect of Increasing Life of equipment on As-it-is stock

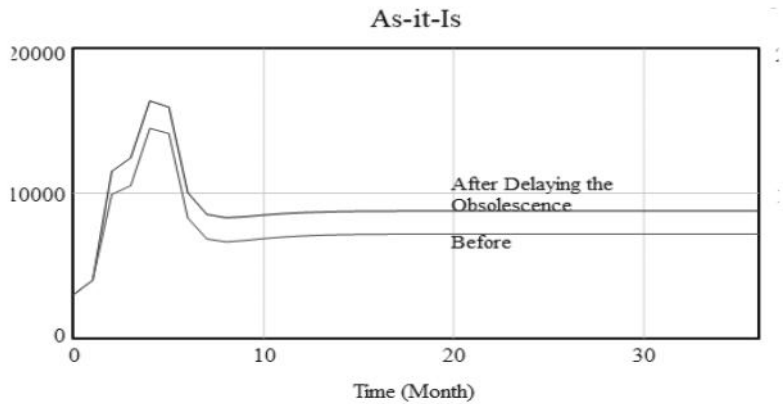


Figure 7: Effect of Increasing Life of equipment on Refub stock

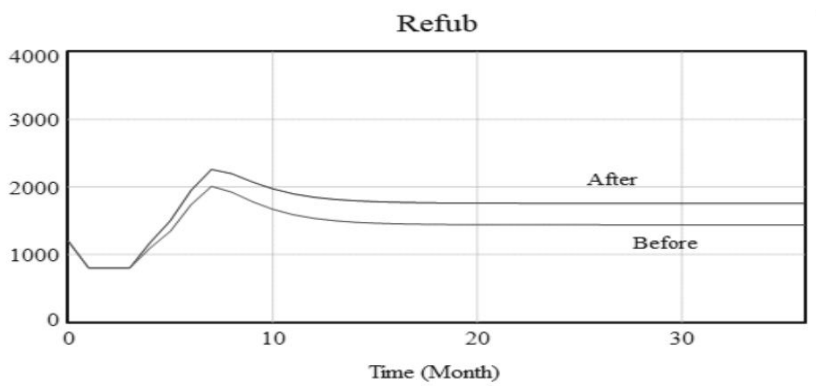
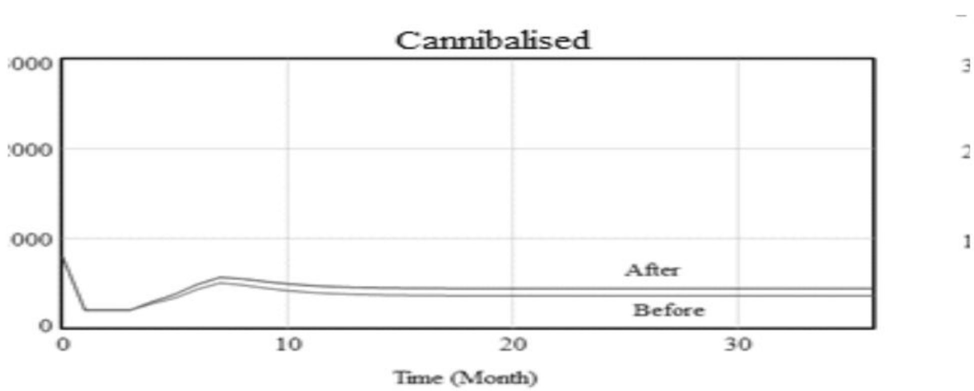


Figure 8: Effect of Increasing Life of equipment on Cannibalised



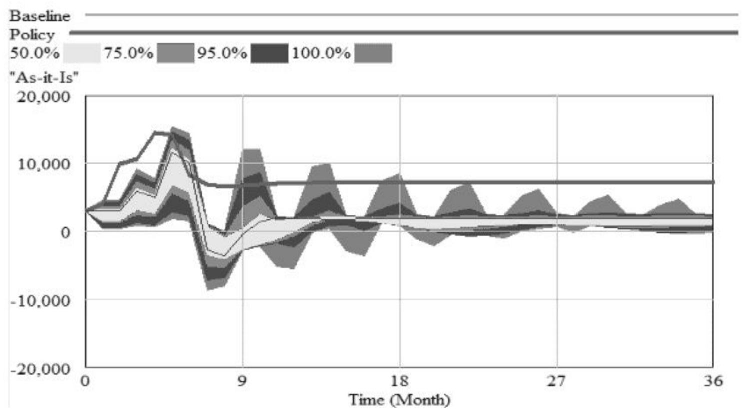
It can be seen that although the three stocks AS-it-is, Refub and Cannibalised Stock increase with this intervention but the increase is more pronounced in the As-it-is case.

Sensitivity Analysis for Green Dust Policies

This test assesses changes of model output behaviour given a variation of input parameters. It can examine the degree of robustness of model and hence indicate to what degree model-based policy recommendations are affected by uncertainty in parameters. In this test, we use the Random Triangular Distribution and the simulations results are displayed as confidence bounds. Other parameters are held constant; we change the parameters GDP1 and GDP2.

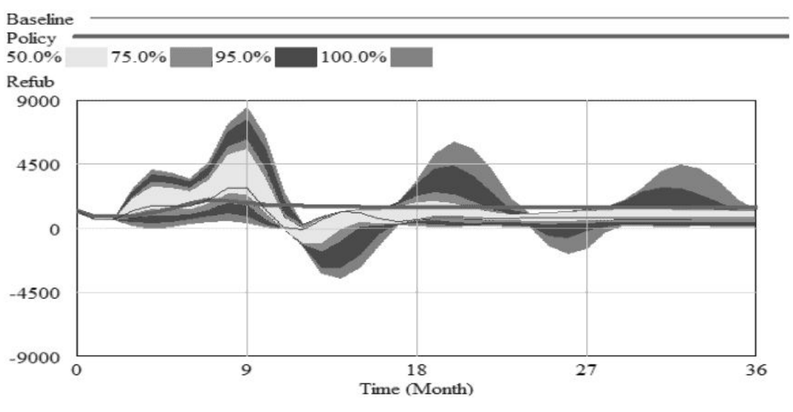
Sensitivity of As-it-is and Refub stocks as we change the GDP1 parameter is listed in Figure 9 and Figure 10 below. The GDP 1 is taken as Random Triangular Distribution with minimum value zero maximum value 1 and peak value as 0.5.

Figure 9: Sensitivity of As-it-is to change in GDP1



The figure 10 below depicts the sensitivity of Refub stock to change in GDP1 as described earlier.

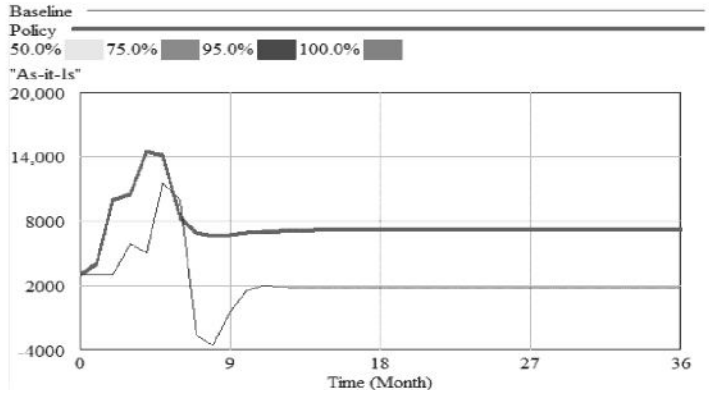
Figure 10: Sensitivity of Refub to change in GDP1



As it is evident from the Figure 10 and Figure 11 As-it-is and Refub both stocks are sensitive to the Green Dust Policy, GDP1.

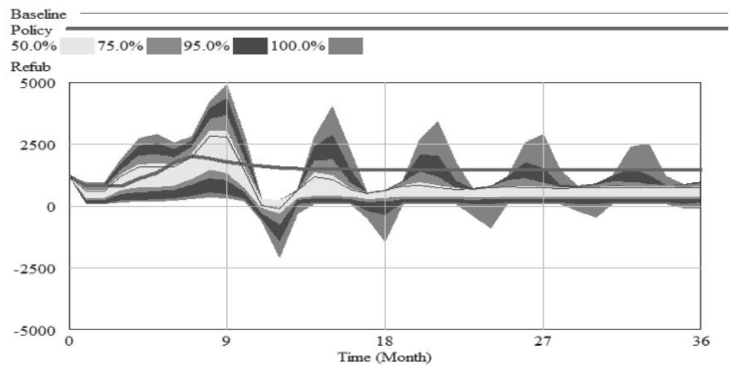
Sensitivity of As-it-is and Refub stocks as we change the GDP2 parameter is listed in Figure 11 and Figure 12 below. The GDP 2 is taken as Random Triangular Distribution with minimum value zero maximum value 1 and peak value as 0.5.

Figure 11: Sensitivity of As-it-is to change in GDP2



The figure 12 below depicts the sensitivity of Refub stock to change in GDP2 as described earlier.

Figure 12: Sensitivity of Refub to change in GDP2



As it is evident from the Figure 11 and Figure 12, the As-it-is stock is not sensitive to the changes in Green Dust Policy, GDP2. On the other hand, the Refub stock is sensitive to the changes in GDP2.

Managerial Implication

The managerial implication of this research is in devising quality policy for the different levels of sorting and how it would impact the different stocks. Based on this the total revenue realized would be impacted. The life of the product and the obsolescence is also a factor that can influence the chain and the profitability.

Conclusion

In this study, we analysed a reverse logistics firm and applied the system dynamics model. Firstly, the operations in the organization were mapped to a causal loop diagram to understand the direction of the impact. The stock and flow diagram was drawn. Based on the initial values the model was validated. Further, the life of the equipment also has an impact on the stocks and thereby revenue of the organization. made.It is observed that stricture quality policies can enhance the revenues for the organization.

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