Inventory Control in Closed Loop Supply Chain using System Dynamics

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Abstract

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. In this study, we explore a System Dynamics approach in order to model an inventory control system for a remanufacturing process in the context of a Closed Loop Supply Chain. Specifically, the return process is modelled using several factors which influence relationships within the process. The factors considered are residence time of the product with customer, service agreement with customer and customer behaviour in returning used products. The findings suggest that a reduction of residence time and an increase in the level of service agreement with customers, which in turn increases customer behaviour in returning used product, can lead to efficiency in inventory management for companies involved in the remanufacturing process. In addition, we provide two simple case studies to support these findings.

Key words: System Dynamics, Inventory Control, Remanufacturing, Closed Loop Supply Chain.

1 Introduction

Many companies have realized that reverse logistics is an important competitive and strategic part of their business mission. The usage of reverse logistics in the business sector is increasing not only because of the implementation of more stringent environmental regulations, but also because of competitive reasons. The results of a survey, which involved 1,200 logistics managers and more than 150 managers with reverse logistics responsibilities in the U.S., found that 65% of companies believe that returns management is an important strategic tool for their business (Rogers and Tibben-Lembke, 2001). Generally, returns can be classified into three major areas:

manufacturing, distribution and market returns (de Brito, Dekker and Flapper, 2004). The first two areas are related to the process of manufacturing and distribution such as returns from surplus of raw material and quality control as well as product recalls and B2B commercial returns. The last area concerns users of products and involve warranties, end of product use and end of life returns.

A number of studies describe the role of reverse logistics in economic and environmental activities during the product development process. Particularly, several models have been developed to support managerial decision making and to optimize processes in different reverse logistics areas. The scope of these models is mostly to optimize costs or profit through an analysis of the parameters and variables as defined in the modeling method. However, it becomes evident that a concept differentiation between Reverse Logistics and Closed Loop Supply Chain is necessary. The closed loop supply chain concept refers to a possible integration between reverse and forward supply chain. Traditional activities such as collection and distribution planning, inventory control and production planning have to be scheduled and planned while also considering the returns flow.

Inventory control requires appropriate control mechanisms to integrate the return flow of used products with the material planning for the forward flow (Fleischmann et al. 1997). This can vary for different reverse logistics situations. For example, for some companies whose business is recycling, returns are the only inventory resource for the forward production process in which used products or materials are the only raw material. Traditional inventory control methods might be satisfactory in these situations. 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. Hence, inventory management is complicated particularly by remanufacturing activities since key information such as on hand inventory, lead time and yield are not clear in this process (Toktay, Wein and Zenios, 2000). Several inventory models for the remanufacturing process have been developed where returns are exogenous variables, without any correlation between sales and returns. Many authors use simple assumptions regarding the return process such as homogeneous Poisson Process for demand and/or return flow and returns independent from the demand (de Brito and Dekker, 2003). Thus, in this paper, we try to avoid such assumptions through the use of particular factors such as residence time of the product with customer, service agreements or incentives developed by companies for the recovery of used products and customer behaviour. These factors can affect the return process of used products and influence the uncertainty in the returns flow as they can provide a forecast method for the quantity and timing of returns.

In this paper, we use System Dynamics (SD) (Forrester 1958, 1961), a methodology for studying and managing complex feedback systems, particularly business and social systems, to model an inventory control system for a remanufacturing process in which production is integrated with remanufacturing activity. Our objective is to analyse, through the simulation of the SD model, the trend of the total inventory cost influenced by a returns rate which is affected by the external factors previously mentioned. In order to model this system, we consider a pull inventory control strategy without considering disposal of recoverables and lead time. Moreover, we model the returns process where

demand and returns are correlated. Uncertainty in timing and quantity of returns is specifically tackled through relationships of parameters which can provide quantity and time of return for used products with different product characteristics and in different industries. We also present the practical implication of our findings through information collected by two companies directly involved in reverse logistics and remanufacturing activity.

2 Literature Review

Remanufacturing systems has been increasingly researched by several authors who have developed several models for different industry contexts. A number of these focus on production planning and inventory control for product remanufacturing. The objective of inventory management is to control external components orders and the internal component recovery process to guarantee a specific service level and to minimize inventory costs. Additionally, in the case of remanufacturing, if it may actually be cheaper to overhaul a return than to produce or to buy a new one (Fleischmann et al. 1997).

The review has followed two main streams: (1) inventory control in a remanufacturing context and (2) application of SD modeling for remanufacturing systems.

2.1 Inventory control models

An inventory control model was developed in order to compare procurement and inventory control strategies and to determine an optimised approach based on cost minimization (van der Laan, Dekker and Salomon, 1996). The scope was to compare different procurement and inventory control strategies in order to find the optimal one, based on the minimal costs, through scenarios in which parameters are varied. A similar model was analysed in order to find the optimal serviceable inventory level and procurement order that minimized total inventory/production cost (van der Laan et al. 1996). In a different way from the previous two models, a production planning and inventory control system was developed tackling more explicitly the push and pull inventory strategy on remanufacturing and disposal activities (van der Laan and Salomon, 1997). A comparison between the push and pull inventory strategy based on the optimal total system costs is analyzed in their model. The result shows that pull is preferred to push strategy if recoverable inventory is lower than serviceable inventory. This is generally because holding costs for serviceable inventory are higher than recoverable inventory holding costs and the pull strategy keeps remanufacturable items in the recoverable inventory.

The effects of leadtime duration and variability on total cost in an hybrid manufacturing and remanufacturing system is the topic of another inventory control model (van der Laan, Salomon and Dekker, 1999). They used the same model and total system costs of van der Laan and Salomon (1997) but without considering disposal of recoverables as a possible inventory strategy. Through their analysis, it follows that an increase of manufacturing and remanufacturing leadtime leads to an increase of total costs for both push and pull inventory strategy. This could be due to a common production operation management theory whereby increasing the leadtime, without changing the reorder point or the order batch, increases the probability of backorder and consequently a larger amount of safety stock can be used. Moreover, the results point out that for such inventory systems pull is favoured over push strategy as it lowers serviceable inventory holding costs. This is the case for systems where the serviceable inventory holding cost

is larger than the recoverable inventory holding cost, the leadtime is considered stochastic and the priority is given to remanufacturing as opposed to manufacturing in order to reduce recoverable inventory holding cost. The same result is valid for systems with large return rates.

Another research model is also based on the serviceable inventory level (Kiesmuller and Minner, 2003). This study focuses on an inventory model where the serviceable inventory is fed by production and remanufacturing without considering the procurement and disposal option and without lingering over a push or pull strategy. Through a stochastic product recovery inventory system, the authors developed a model with a news vendor type formula approach. The objective was to find the optimal produce up to level and remanufacture up to level which minimize the total inventory costs. A similar model was developed in the same period in which it is pursued a similar objective (Kiesmuller 2003). However, in this case the push and pull policy strategies were investigated. A recent study on production planning and inventory control in remanufacturing engines for vehicles considers planned lead time as a decision variable (Tang, Grubbström and Zanoni, 2007). In this case a different approach was taken by the previous inventory control models, as this study analyses specific remanufacturing activities such as disassembly and reassembly without considering remanufacturable or serviceable inventory process.

Deterministic Economic Order Quantity (EOQ) model is another approach to inventory control system in the remanufacturing context (Teunter 2001). This model considers general policies as an alternation between manufacturing and remanufacturing batches, the presence of disposal with rate variation and different holding cost rates between manufactured and remanufactured items. Following the same topic, a deterministic model for an inventory system was developed where the demand is satisfied by recovered products and newly purchased products (Koh et al. 2002). Particularly, they use a joint EOQ and Economic Production Quantity (EPQ) model where, different from Teunter (2001), one setup/batch for recovery and many orders for new purchased products, or vice versa, are simultaneously considered.

2.2   System Dynamics and remanufacturing

The complexity of reverse logistics processes has motivated several researchers to use System Dynamics modelling techniques in the search for better strategies and policies for integrating the forward and reverse supply chains. However, there is still a lack of System Dynamics research for closed loop supply chains (Kumar and Yamaoka, 2007).

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 and 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 cost decreases when higher remanufacturing capacities are reached. In another similar study using System Dynamics (Georgiadis and Vlachos, 2004b), the impact of environmental influences and remanufacturing capacity planning policies were simulated using the 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 modelled

in their systems included: supply, production, distribution, usage, returns collection, inspection, remanufacturing and waste disposal.

A remanufacturing system was modelled 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 and Tagaras, 2006). Two concepts were introduced in the study: *residence time* and *residence index*. *Residence time* is defined as the time the product stays with the customer before it is returned while *residence index* represents the ratio of the average residence time over the length of the product lifecycle. The residence index represents the tendency of the product to stay and be used by the customer during its lifecycle. It can be used to classify different products as to their suitability to be remanufactured or not. Their research focused mainly on the effect of the product lifecycle on capacity planning. Thus, our motivation for this present research is that so far in reverse logistics literature, no study could be found on the effects of returns rate and uncertainty in quantity of returns on total production.

3 Methodological approach

System Dynamics is a computer aided method for analysing and solving complex problems, particularly on policy analysis and design with several applications including corporate planning and policy design, economic behaviour, public management, biological and medical modeling, energy and environment, social science, dynamic decision making, complex non linear dynamics, software engineering and supply chain management (Angerhofer and Angelides, 2000). 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 modeller 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 analyse 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 behaviour of a real process model. The tests, which are grouped as *direct structure tests* and *structure oriented behaviour tests*, provide a formal and logical process for model validation (Barlas 1996). *Direct structure tests*, for which simulation is not involved, compare each mathematical equation of the model with the

available knowledge from a real system. These tests utilise 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. On the other hand, *structure oriented behaviour tests* or indirect structure tests involve simulation of the entire model and they apply structure model validation through a quantitative comparison with the real system. Several comparison tests can be applied such as extreme condition and behaviour sensitivity tests. The first test compares the model and the real system behaviour under the same extreme values for selected parameters. In a different way, the second test compares the high sensitivity of particular parameters between a model and the real system.

In order to support and clarify some of the findings obtained through the simulations analysis, the methodological approach of this study involves two simple case studies. These employ data from companies involved in reverse logistics and remanufacturing processes. The data were obtained through interviews with company management and through existing literature. The companies involved were The Australian Mobile Telecommunication Association (AMTA) which through the MobileMuster program has started the official national recycling program of mobile phones, and Fuji Xerox Australia which is involved in remanufacturing of assemblies and sub assemblies of printers and copiers. The Fuji Xerox interviews were conducted at the Eco Manufacturing Centre located in Sydney.

4　Problem and model formulation

Our study is based on a single product remanufacturing system within the context of Closed Loop Supply Chain which involves several operations such as: production, collection and inspection of used products, remanufacturing and disposal. Our focus in this study is on the return of products from customers/products users at the end of their useful life, other returns such as product recalls and B2B commercial returns are excluded in the study. Figure 1 shows the remanufacturing process considered in this paper. The forward supply chain involves production of new products to fulfil customer demand. After product use, returns are collected, inspected and either stored as remanufacturable/recoverable inventory or disposed of depending on whether the quality of returns is suitable for remanufacturing according to the company's quality standard policy. The serviceable inventory, used to fulfil external demands, is fed by the production of new or remanufactured products which are as good as new. Production and manufacturing are important components of any remanufacturing system. Equally important to the process is analysis and decision making regarding inventory, operational and marketing activities.
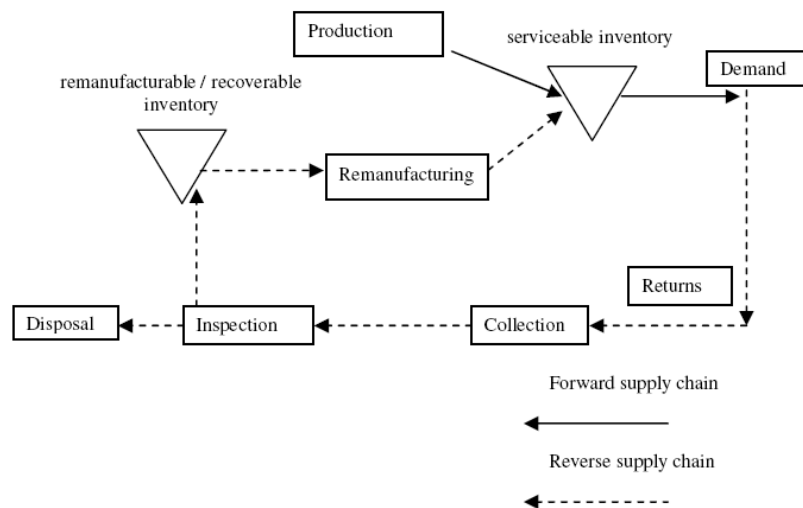
Figure 1: Remanufacturing Process

A number of assumptions have been made throughout this analysis in order to simplify the system and its interpretation:

- Uncontrollable disposal has not been considered: instead of the product returning to the remanufacturer, it is disposed of in an uncontrolled manner, sometimes opposing the manufacturer's instructions or environmental regulations.
- The planned disposal of recoverable inventory has not been considered.
- The capacity of several activities such as collection, remanufacturing and production are considered infinite.
- Backordering and lead times have not been considered.

In the model, the returns rate incorporates uncertainty in quantity and timing of returns and a pull inventory control system is applied. This system is obtained through re-order point inventory replenishment policies which are basic features of several industries in the context of supply chain/inventory planning. The returns rate, which is used to calculate the number of returns after the time of use, is represented as the ratio between the probable returns flow of sold products and the demand. The probable returns flow and the time of use are calculated through the relationship between the main factors which characterize the model of this study - *return index* and *residence time*. The latter is the factor defined in the study of Georgiadis, Vlachos and Tagaras (2006).

The ways in which companies manage the return process of the products sold to the customers, through service agreements and sale contracts with retailers or the customers themselves, can influence the returns rate and particularly the quantity of returns. For example, leasing contracts make sure that almost all products are returned after the residence time. In the model, the *service agreement with customer* factor is used in order to relate the quantity of returns with the demand for different products in different industries. Moreover, *customer behaviour* is another factor which can influence this relationship. The attitude of the customer's return activity and response to company's returns process incentives can affect the returns rate and in particular the likelihood of a particular product to be returned. Hence, the *return index* is obtained by considering the relationship between company incentives/service agreements developed in order to

recover used products and actual customer behaviour in returning products. Simply, it is the tendency of the product to be returned by the customer during its lifetime. This tendency varies among different products and industries. This is explained in further details afterwards.

4.1. Causal loop diagram

The CLD representing the remanufacturing model is presented in Figure 2. The behaviour of the system is defined by seven negative feedback loops 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 (Sterman 2000). Therefore, if the process presents outputs far from the target level, a negative feedback generates corrective actions to bring the process toward the desired value.
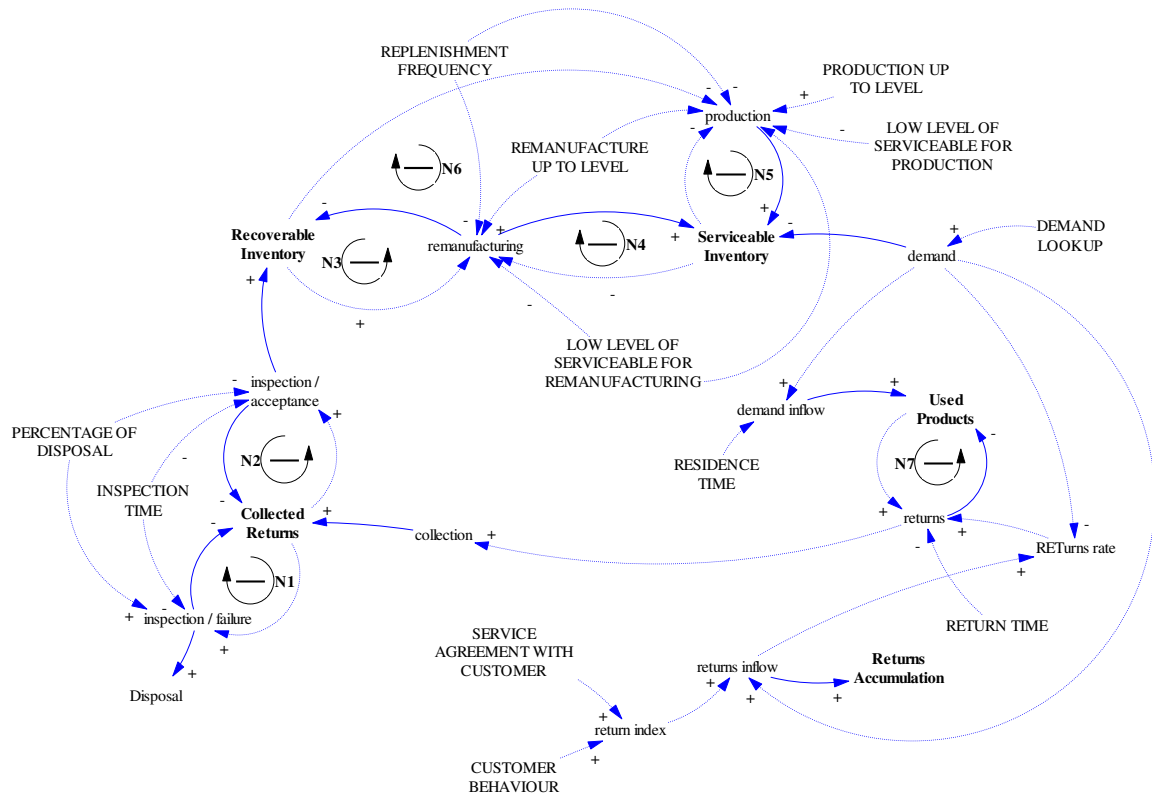

Figure 2: Causal loop diagram

The behaviour of the collection activity in this remanufacturing process is represented by two negative feedback loops, N1 and N2. These are shown in Figure 3 and Figure 4 respectively. An increase in *returns* increases the rate of *collection* which in turn increases the level of *Collected Returns*. At this stage, returned products are inspected in order to check for their quality and remanufacturability. Figure 3 shows the inspection process in the case of a failure of the quality test.
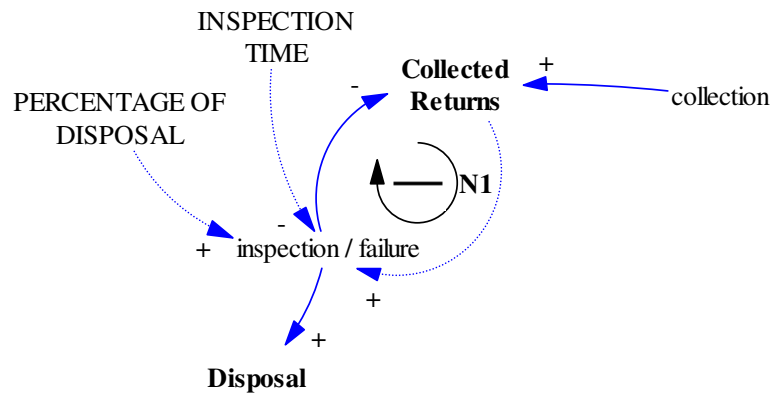
Figure 3: Collection loop N1

Failed items decrease the level of *Collected Returns*, through an *inspection/failure* flow and at the same time increase the level of *Disposal* which represents the quantity of non-reusable items that are disposed of. The flow rate of failed items depends on the value of *PERCENTAGE OF DISPOSAL* and *INSPECTION TIME*. The former affects it positively as its change leads to a similar change in the quantity of failures. For example, an increase in the percentage value of disposal leads to an increase in the flow of failed items during the time period. *PERCENTAGE OF DISPOSAL* represents the quality standards policy of the company and is affected by several parameters and techniques used to check the returned items. It is defined as an average percentage of collected returns disposed of and differs for different products and different quality standard policies used (Vlachos, Georgiadis and Iakovou, 2007). *INSPECTION TIME* represents the required period of time to inspect the collected items. This negatively affects the inspection flow as a faster/slower inspection leads to an increase/decrease of the flow. Since an increase in *Collected Returns* causes an increase in *inspection/failure* and which in turn causes a decrease in *Collected Returns*, a negative feedback loop (N1) is created.
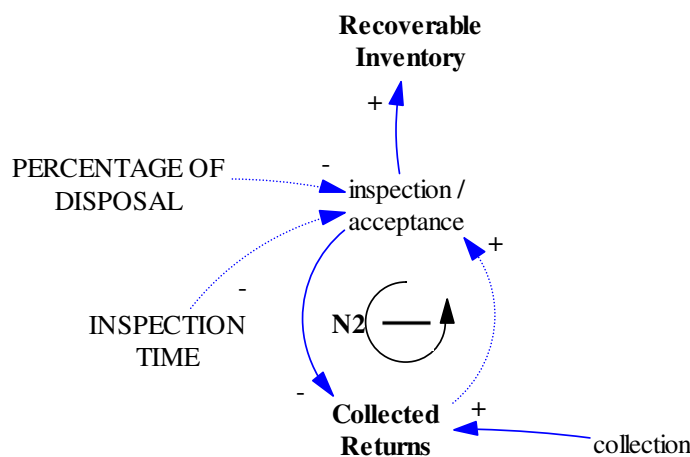

Figure 4: Collection loop N2

The inspection process, in the case of acceptance at the quality test for remanufacturable items, is shown in Figure 4. Accepted items increase the level of *Recoverable Inventory*

that are ready to be remanufactured through the *inspection/acceptance* flow. The flow rate of accepted items depends inversely on the value of *PERCENTAGE OF DISPOSAL*, as a lower percentage of disposed items of leads to higher level of remanufacturable items. Thus, an increase in *inspection/acceptance* rate causes a decrease in *Collected Returns* level, which in turn causes a decrease in *inspection/acceptance* rate, hence forming the negative feedback loop N2.

The remanufacturing activity behaviour in the process is represented by two negative feedback loops, N3 and N4. These are shown in Figure 5.
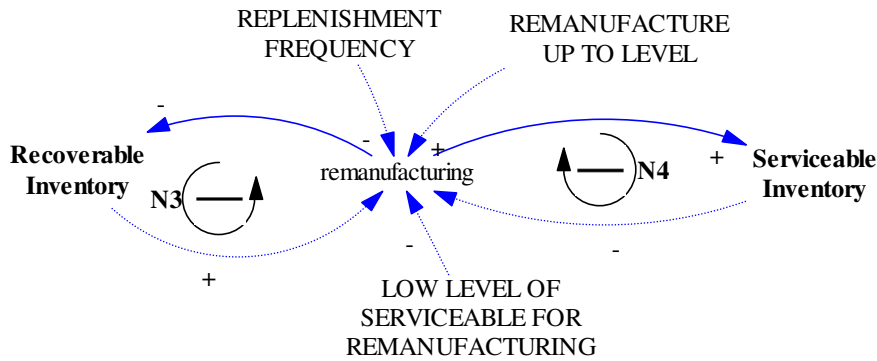

Figure 5: Remanufacturing loop N3 and N4

Remanufacturable items are stored as *Recoverable Inventory* from which items are used for remanufacturing purposes when necessary and stored as *Serviceable Inventory* in order to fulfil customer *demand*. An increase in the *Recoverable Inventory* level increases the *remanufacturing* rate which in turn decreases the *Recoverable Inventory* level forming the negative feedback loop N3. Similarly in the negative feedback loop N4, an increase of *remanufacturing* levels increases the *Serviceable Inventory* level which in turn decreases the level of *remanufacturing* activity. Thus, inventory levels have both positive and negative effects on the *remanufacturing* rate in order to control the flow of remanufacturing items and achieve balance in the inventory system. Moreover, *remanufacturing* flow is negatively affected by the *REPLENISHMENT FREQUENCY* of the inventory. Replenishment frequency represents the time period on which is based the replenishment of remanufacturing orders and an increase/decrease of its value generally leads to a decreased/increase of the order size.

Remanufacturing occurs when necessary in a pull inventory strategy because remanufacturing is preferred to a more expensive production activity. Several models in literature discuss push and pull inventory strategies in a remanufacturing system (Kiesmuller 2003; van der Laan and Salomon, 1997; van der Laan, Salomon and Dekker, 1999). In Figure 5, *Sr (REMANUFACTURE UP TO LEVEL)* and *sr (LOW LEVEL OF SERVICEABLE FOR REMANUFACTURING)* are two variables which affect the *remanufacturing* rate and are used for implementing a pull strategy in the system. *Sr* represents the upper value limit for remanufactured batches while *sr* represents the lower value for remanufactured batches as well as the level of a *Serviceable Inventory* for which a remanufacturing batch is required. *Sr - sr* represents the level of *Recoverable Inventory* for which it is possible to produce a remanufacturing

batch. A more detailed explanation of the inventory pull strategy is given in Figure 6 which shows the usage of inventory over time in a remanufacturing system.

Figure 6 is similar to van der Laan, Salomon and Dekker's (1999) who also did not consider disposal of recoverable inventory. The pull strategy is represented by the *Recoverable Inventory* level. When this level exceeds ($Sr - sr$) (i.e. the level at which it is possible to make a remanufacturing batch) disposal of items does not occurs. Remanufacturing occurs only when necessary and is represented by *sr*, the level of *Serviceable inventory*. This strategy increases the cost of the *Recoverable Inventory* but reduces the cost of the *Serviceable Inventory* which is usually more expensive. Remanufacturing is preferred to production, as *sm* (the *Serviceable Inventory* level at which a production batch is required) is lower than *sr*.
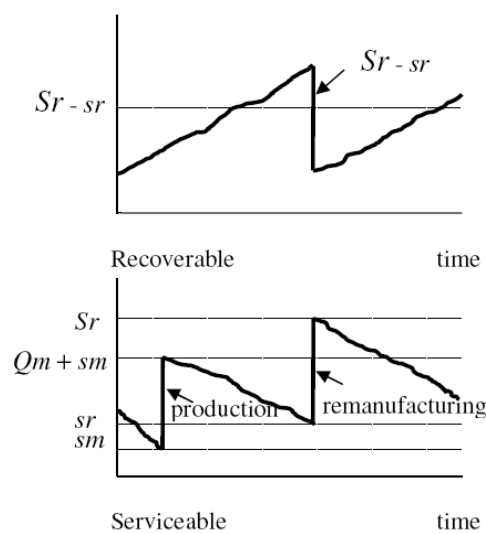

Figure 6: Usage of inventory in remanufacturing system

Produced items increase the *Serviceable Inventory* level in order to fulfil customer *demand*, as Figure 7 shows. In the system, *production* is only used to increase the *Serviceable Inventory* level when *remanufacturing* is below *Recoverable Inventory* as shown in Figure 6. Two additional variables which affect production flow are used to implement the pull inventory strategy: *Qm* (*PRODUCTION UP TO LEVEL)* is the upper value for production batches and *sm* (*LOW LEVEL OF SERVICEABLE FOR PRODUCTION)* is the level of serviceable inventory at which a production batch is required. However, production flow is mainly affected by *Sr* and *sr*, because it is only when the *Recoverable Inventory* level is lower than *Sr - sr* and the *Serviceable Inventory* level reaches *sm* that a production batch is manufactured and stored in *Serviceable Inventory*. The negative feedback loop N5 creates a balance between *production* flow and *Serviceable Inventory* level.
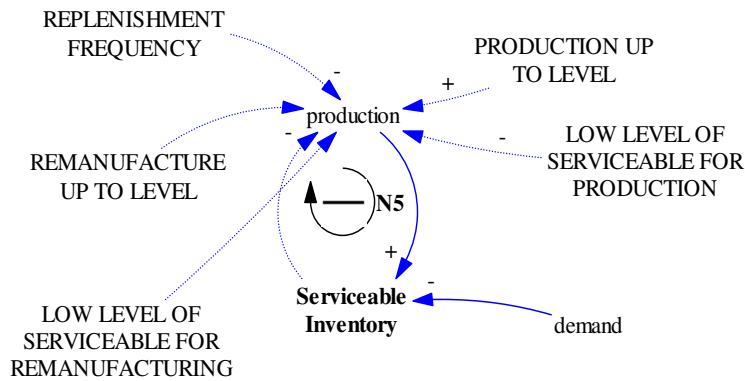
Figure 7: Production loop N5

The negative loop N6 involves both the *production* and *remanufacturing* flows and both the *Recoverable* and *Serviceable Inventory* level as shown in Figure 8. In this remanufacturing system a balance among these variables, which involves a control process between inventory levels and flow of items, is required. For example, if the physical flow of items produced increases, the *Serviceable Inventory* level increases. In order to prevent a continuous accumulation of serviceable items (without considering depletion from customer demand), *Serviceable Inventory* affects negatively the *remanufacturing* flow which consequently decreases. This leads to an increase of *Recoverable Inventory* level and consequently, due to the negative relationship between *production* and *Recoverable Inventory*, *production* flow decreases. In this way the system is driven towards a balancing goal.
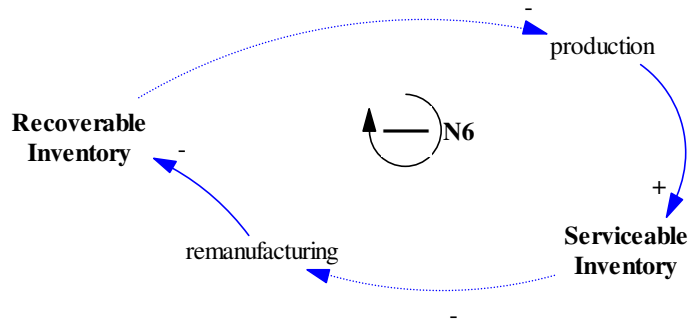

Figure 8: Inventory loop N6

The behaviour of negative feedback loop N7 (Figure 9) is caused mainly by *Used Products* and *returns* as well as several variables representing the influence relationships between the forward and reverse logistics.
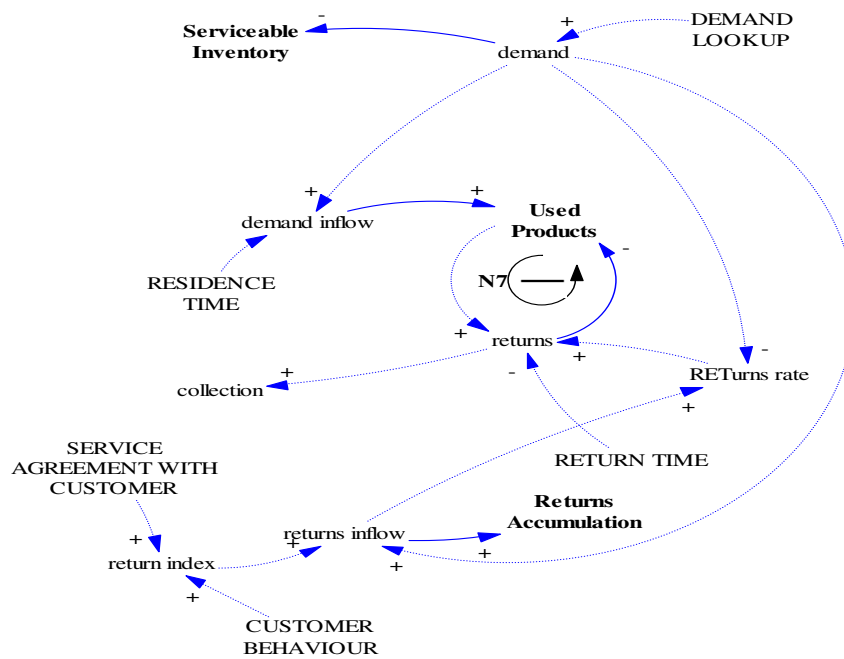
Figure 9: Used products loop N7

The process starts with customer demand which depletes *Serviceable Inventory* level. Product demand or sales are defined by external historical data represented by *DEMAND LOOOKUP*. After a period of time or *RESIDENCE TIME*, products in use can be considered as used products. This is represented by the flow between the rate variable *demand* inflow and the level of *Used Products*. The variable *RESIDENCE TIME* is the average time that a product stays with its customer before it is returned (Georgiadis, Vlachos and Tagaras, 2006). This period of time varies for different kinds of products and different customer behaviours. This variability represents the uncertainty which affects the timing of returns in a closed loop supply chain. For this reason, in this model, not all used products are considered as returns but as possible returns after an average period of use which characterizes the kind of product. Part of these used products become *returns* which are consequently collected. This is represented by the physical flow for which *returns* deplete the *Used Products* level and the information flow between *returns* and *collection*. Also in this case, the level of used products affects and controls the flow of returns, generating the negative loop N7, which characterizes the possibility that not all used products are returned at the same time.

Uncertainty in the quantity of used products returned by customers negatively affects collection, remanufacturing, production planning and inventory control. For this reason, several variables, shown in Figure 9, are used to reduce the effect of uncertainty and set the quantity of returns. The *return index* is used to set the number of returns from the customer demand. This is represented by the *returns inflow* which is influenced by *returns index* and *demand*. Two parameters influence *return index*: *SERVICE AGREEMENT WITH CUSTOMER* and *CUSTOMER BEHAVIOUR*. The former 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. The latter parameter defines the attitude of the customers in returning used products and their response to the company incentives in increasing the return process. The relationships among these three factors are shown in Figure 10. The difficulty in obtaining and documenting real data has led to the use of a distributional form made on intuitive grounds. However, a similar approach for an influence analysis is presented by Georgiadis and Vlachos (2004b) who analyse different parameters such as market behaviour and the green image factor for products in different industries.

In Figure 10 *return index* for a particular product is obtained from the percentage of service that the company offers to the customer to take back the product after its use. Therefore, the values of *SERVICE AGREEMENT WITH CUSTOMER* are between 0 and 100% which correspond to 0 and 1 of *return index* respectively. High values of service agreement are obtained by companies which offer incentives for a full return of the sold products, for example, leasing contracts (e.g., cars and photocopiers) or service at the end of the useful life of the product/component (e.g., single use cameras and toner cartridges). Also included are companies which have full responsibility for recovery due, for example, to environmental Government regulations. High values of service agreement correspond to high values of *return index* for which it is assumed that almost all the demands or sold products are returned by customers. The minimum value corresponds to the kinds of products not involved in reverse logistics activity, particularly remanufacturing, with a zero return index and no efforts from companies in products recovery. Regarding the in-between values, the dependency between the index and service agreement depends on *CUSTOMER BEHAVIOUR* (CB).
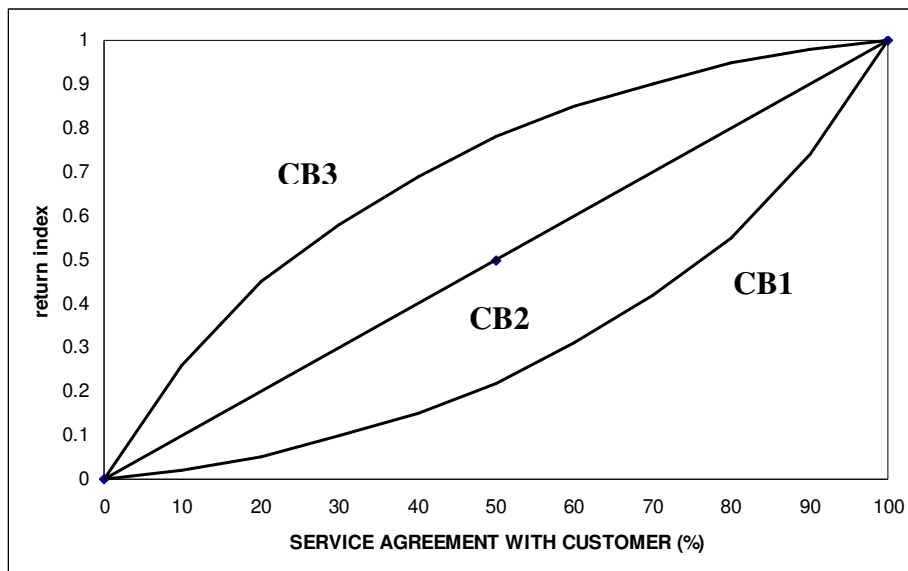

Figure 10: Relationship between *SERVICE AGREEMENT WITH CUSTOMER* and *return index* for various *CUSTOMER BEHAVIOURS*

Several company incentives are used in practice to stimulate a desired behaviour in the context of product recovery (de Brito, Dekker and Flapper, 2004). These can be: a deposit fee that has to be paid when purchasing the product, free collection or repurchase of used products, monetary incentive paid at the return of used products and

trade-in which involves the possibility of obtaining a newer version of a product only if the original product is returned. Currently, appropriate product designs for easier disassembly and clear information/advertising about reverse logistics activities and environmental responsibilities are being developed by companies in order to assure the return of used products. However, the sensitivity and reaction to these incentives depends on individual customer behaviour. To incorporate differing customer behaviours into the study, three alternative curves are assumed in Figure 10. CB2 corresponds to a proportional relationship between *SERVICE AGREEMENT WITH CUSTOMER* and *return index*. In this case, it is assumed that customers respond proportionally to incentives and services offered by companies attempting to recover used products. The symmetric curves CB3 and CB1 correspond to a quicker and slower response from customers respectively. Particularly for CB3, it is assumed that the response of the customers and consequently the associated *return index* changes quickly for low values of *SERVICE AGREEMENT WITH CUSTOMER* while is almost the same for higher values. This is different for CB1 which becomes more acute for higher values of *SERVICE AGREEMENT WITH CUSTOMER*. This theoretical influence analysis is used to involve as much as possible the relationship between customer behaviour and quantity of returns.

4.2. Stock and flow diagram

Figure 11 shows the stock and flow diagram of the causal loop diagram shown in Figure 2.
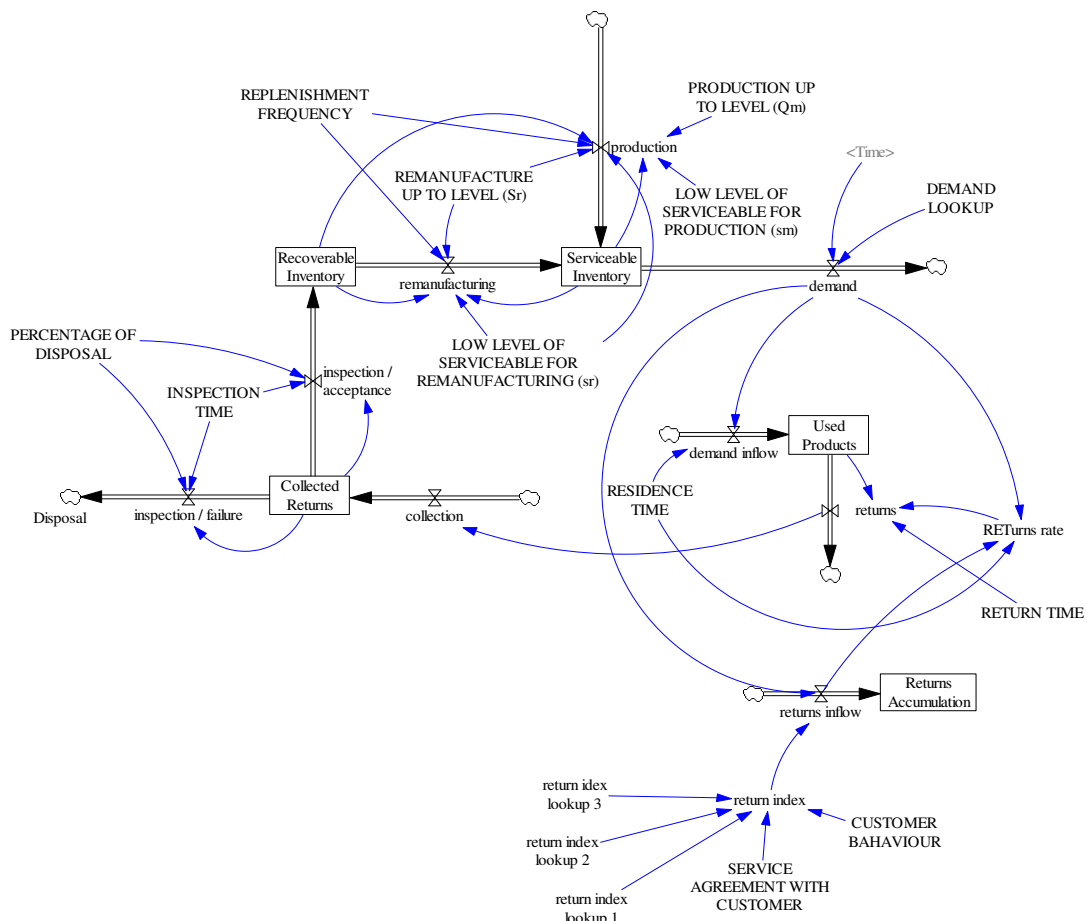

Figure 11: Stock and flow diagram

Rectangles represent level or stock variables which are accumulations of items while valves represent rate or flow variables which are the physical flows of items feeding or depleting the stocks. The physical flow of items is represented by a double line with arrows while flow of information (connection among variables and their relationships for mathematical formulations) is represented by a single line with arrows. Auxiliary variables shown in all upper case letters represent constants while those in lower case letters represent converters used in calculations.

The dynamic behaviour of the remanufacturing system is implemented by a set of mathematical equations. The symbology and the form used for the equations follow the conventions of the simulation software used to build the model: Vensim PLE v5.6d.

The dynamic behaviour of the level variables such as *Collected Returns*, *Recoverable*, *Serviceable Inventory* and *Used Products* is given by a time integral of the net inflows minus the net outflows.

The *collection* flow is equal to the *returns* flow. This means that at time *t*, all returns follow a collection process; *collection (t) = returns (t)*. Infinite collection capacity is assumed as all the possible returns are collected.

Failed returns at time *t* are equal to total *Collected Returns* times the *PERCENTAGE OF DISPOSAL* divided by the *INSPECTION TIME*. The percentage of disposed returns and the inspection time are considered constant due to the difficulty in representing and modeling the real dynamic variance for this factor which depends on product characteristics, company quality policy and inspection strategy. This particular issue is not within the scope of this study. Accepted returns at time *t* are the *Collected Returns* that passed the inspection process. For this reason, the percentage of returns accepted for remanufacturing is 1 – disposal percentage:

$$inspection\,/\,acceptance\,(t) = \frac{Collected\ Returns(t) * (1 - PERCENTAGE\ OF\ DISPOSAL)}{INSPECTION\ TIME}$$

$$inspection\,/\,failure\,(t) = \frac{Collected\ Returns(t) * PERCENTAGE\ OF\ DISPOSAL}{INSPECTION\ TIME}$$

A functional relationship between two variables is used for the formulation of the *demand* at time *t*. This is obtained using a lookup function which allows the definition of customized relationship between a variable and its causes to be defined as a table of values. Table *DEMAND LOOKUP* is defined using historical data for product demand or sales obtained directly from the Global Market Information Database (GMID). This database provides historical data, forecasts and statistics analysis for many countries worldwide on consumer goods in several industries, companies and brands. An equation gives the value of *demand* at any time through a linear interpolation between the values specified in *DEMAND LOOKUP* as *demand (t)=DEMAND LOOKUP (Time)*. Figure 12 shows the function which expresses the relationship between time and demand.
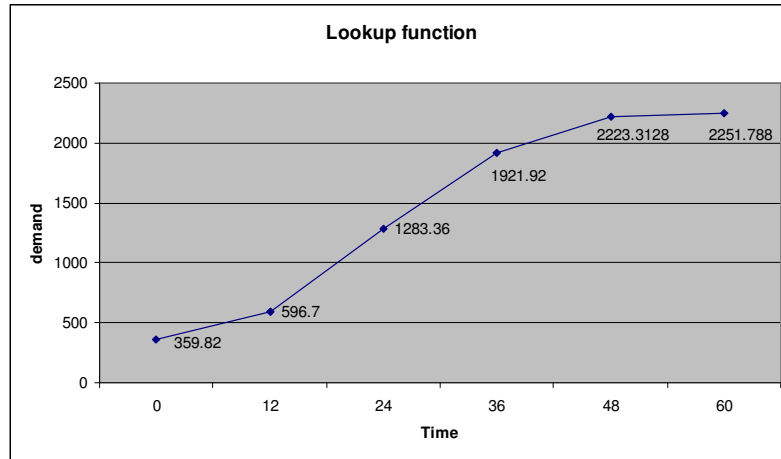
Figure 12: demand lookup

Demand inflow represents the flow of previously sold products currently in use which now are used products and possible returns after the *residence time* has elapsed. In order to model this process the function *DELAY FIXED* is used. This function returns the value of the input *demand* delayed by the delay time which in this case is the *residence time*: *demand inflow=DELAY FIXED (demand, residence time, 0).*

An *IF THEN ELSE* function and the logical operator *AND* are used to define the production quantity in the process. In particular, they provide the number of production reorders during the simulation period. The logical expression defines the condition when the *Serviceable Inventory* level is less than or equal to the *LOW LEVEL OF SERVICEABLE FOR PRODUCTION* and also when *Recoverable Inventory* level is less than *REMANUFACTURE UP TO LEVEL* minus *LOW LEVEL OF SERVICEABLE FOR REMANUFACTURING*. If the condition is true, the expression returns a production reorder equal to the ratio between *PRODUCTION UP TO LEVEL* minus the serviceable inventory on hand and the *REPLENISHMENT FREQUENCY*, otherwise the returned value is zero. A similar equation defines the remanufacturing quantity and the number of remanufacturing orders in the model. In this case, the condition requires that *Serviceable Inventory* level is less than or equal to *LOW LEVEL OF SERVICEABLE FOR REMANUFACTURING* and that *Recoverable Inventory* is greater than or equal to *REMANUFACTURE UP TO LEVEL* minus *LOW LEVEL OF SERVICEABLE FOR REMANUFACTURING*. The possible returned values are a remanufacturing order equal to the ratio between *REMANUFACTURE UP TO LEVEL* minus *LOW LEVEL OF SERVICEABLE FOR REMANUFACTURING* and *REPLENISHMENT FREQUENCY*, if the condition is true, or zero otherwise.

The variable *return index* is formulated through a combination of *IF THEN ELSE* and lookup functions. This equation represents the tendency of a particular product to be returned by customers, considering individual customer behaviours and differing levels of service agreement or company incentives. The constant *CUSTOMER BEHAVIOUR* can assume three values; 1, 2 or 3 which define the three different curves in Figure 10. In function of value assumed by *CUSTOMER BEHAVIOUR*, *return index* is calculated through one of the lookup functions whose table of values identify the curves *CB1*, *CB2* and *CB3* respectively. They represent the lookup functions in which *return index* and *SERVICE AGREEMENT WITH CUSTOMER* are the dependent and independent variable respectively.

The flow of actual returned items which are collected is represented as dynamic ratio between the portion of *Used Products* through the use of *a returns rate* and the time required to return and collect the items:

$$returns(t) = \frac{Used\ Products(t)*\ returns\ rate(t)}{RETURN\ TIME}$$

Returns rate represents the portion or percentage of used products which are returned during the time period under consideration. Several authors such as Kiesmuller (2003), Kiesmuller and Minner (2003) and Inderfurth (2005) use returns rate in their models. In order to define the quantity of returns, they consider a returns rate as the ratio between the average returns and the average demands. Consequently, the *returns rate* in this model is represented as dynamic ratio between *returns inflow* and *demand*:

$$returns\ rate(t) = \frac{returns\ inflow(t)}{demand(t)}$$

A function *DELAY FIXED* is used in order to return the value of the input given by the previous ratio delayed by the *residence time* plus one time period. The reason for this delay is due to the necessary time equivalence between the variables *returns* and *returns rate*, as the accumulation of used products and the actual returns flow start one time period after the residence time. *Returns inflow* represents the expected returns of demand or sold products. A forecast of returns is obtained using the *return index*: $returns\ inflow(t) = demand(t)*\ return\ index(t)$

5. Model validation

The structure of the model was directly validated using extreme condition tests (Sterman 2000). Under extreme condition of the inputs values such as zero or infinity, the model should behave as a realistic system. Validation was performed by means of direct tests for the model equations and particularly for the flow equations. Extreme values were assigned simultaneously to all the input variables in order to analyse the value of the output which should be reasonable for a real system under the same extreme condition. The Reality Check function of the Vensim simulation was used to achieve this.

After a direct structure validation through extreme condition tests, we validated indirectly the entire structure of the model through sensitivity analysis. This behaviour sensitivity test, particularly parameter sensitivity, consists of determining the sensibility of the model to the values of particular parameters and comparing this sensitivity of a real system to the corresponding parameters (Barlas 1996). Moreover, sensitivity analysis tests the robustness of the model conclusions to particular assumptions (Sterman 2000). This means that the sensibility of the model due to changes of value for particular parameters should generate changes in the numerical value of the results or in behaviour patterns which can be similar for a real system and in line with the purpose of the model. The parameters chosen to run the sensitivity analysis were *residence time*, *SERVICE AGREEMENT WITH CUSTOMER*, *CUSTOMER BEHAVIOUR*, *PERCENTAGE OF DISPOSAL*, *REMANUFACTURE UP TO LEVEL*, *PRODUCTION UP TO LEVEL*, *LOW LEVEL OF SERVICEABLE FOR REMANUFACTURING* and *LOW LEVEL OF SERVICEABLE FOR PRODUCTION*. The choice was due to their high influence on the behaviour of the system and their uncertainty about the suitable value to use in the model. The first three parameters characterize the uncertainty in timing and quantity of returns. Then they have a high influence on the behaviour of the

system. The other parameters characterize the company strategy and policy in inventory control and inspection activity. Then, because of the generality of the model, they are affected by uncertainty in the reasonable value to use in the model.

6.   Simulation and results

In order to apply scenarios analysis a parameter of study is required. As for most remanufacturing inventory systems the objective is to minimize the average total cost, the latter will be considered for the analysis. However, this study does not try to determine the optimal order quantity or reorder inventory level. Rather the objective is to unfold the effects on the system of factors such as *residence time* and *return index* which are influenced by customer behaviour, product characteristics and service agreements offered by companies. These factors are considered as an event that intervenes in a remanufacturing system where returns process is characterized by uncertainty in quantity and timing of returns. The considered total cost for the analysis is found by adding a number of operational costs. These are the *set-up costs* for each production reorder and remanufacturing order, *cost of stockout* for each out of stock sale and *holding costs* for recoverable and serviceable inventory. The reason for choosing these particular costs is due to several observations. Firstly, the system presents a disposal activity due to the inspection process and not to a planned disposal in recoverable inventory which is usually required because of the limited capacity of the latter. This means that all accepted returns from the inspection are stored as recoverable inventory and used for the remanufacturing activity. Then, there are not inventory decisions which affect the remanufacturing and production activity in terms of quantity of items to be remanufactured and produced (van der Laan and Teunter, 2006). Moreover, the mathematical formulation of the model does not consider production and remanufacturing rate. These observations make the inventory system independent of the remanufacturing and production activity and consequently they exclude the production and remanufacturing costs. However, in order to potentially consider cheaper remanufacturing rather than production activity, (remembering that the cost of remanufacturing is typically 40% - 60% of the cost of production) different set-up costs are assumed for production reorder and remanufacturing order. However, this analysis focuses on the total inventory costs which exclude the collection and inspection/disposal costs.

The *set-up costs* are formulated as the sum product of the fixed set-up costs per reorder or order and the number of production reorder and remanufacturing orders respectively. In this case only the fixed set-up cost is considered while variable set-up costs which involve activities such as transportation and materials handling are ignored. The *cost of stockout* is obtained through the multiplication of the unit cost for a lost sale and the number of lost sales. The latter are found through the negative values of serviceable inventory which represent unfilled demands and consequently lost sales. The recoverable and positive serviceable inventory on hand multiplied respectively by the recoverable and serviceable holding cost per item per time unit gives the inventory *holding costs*. Unit holding cost for serviceable is considered greater than unit holding cost for recoverable as several storing factors such as insurance, taxes, deterioration, damage and capital invested can generate lower costs for the recoverable inventory.

This analysis focuses particularly on the returns process and is obtained through the combination of several values of some parameters for which the system has shown to be sensitive during the sensitivity analysis. The parameters are *RESIDENCE TIME*,

SERVICE AGREEMENT WITH CUSTOMER and *CUSTOMER BAHAVIOUR* for which the returns process system has shown sensitivity in the quantity of returns to different combinations of their values.

The base scenario used for this analysis has the same value of parameters considered for the sensitivity analysis. However, in this case, *demand* is set to a uniformly distributed random number in order to generalize the model to different kinds of products. The random values are set between 300 and 2000 items with a fixed noise seed, in order to have the same sequence of random values for every simulation, equals to 2. The formulation of *demand* is so represented: *demand = RANDOM UNIFORM (300, 2000, 2)*. Moreover, *RESIDENCE TIME* is set to 12 months. Figure 13 shows the costs trend for the base scenario during the planning horizon set to 60 months.
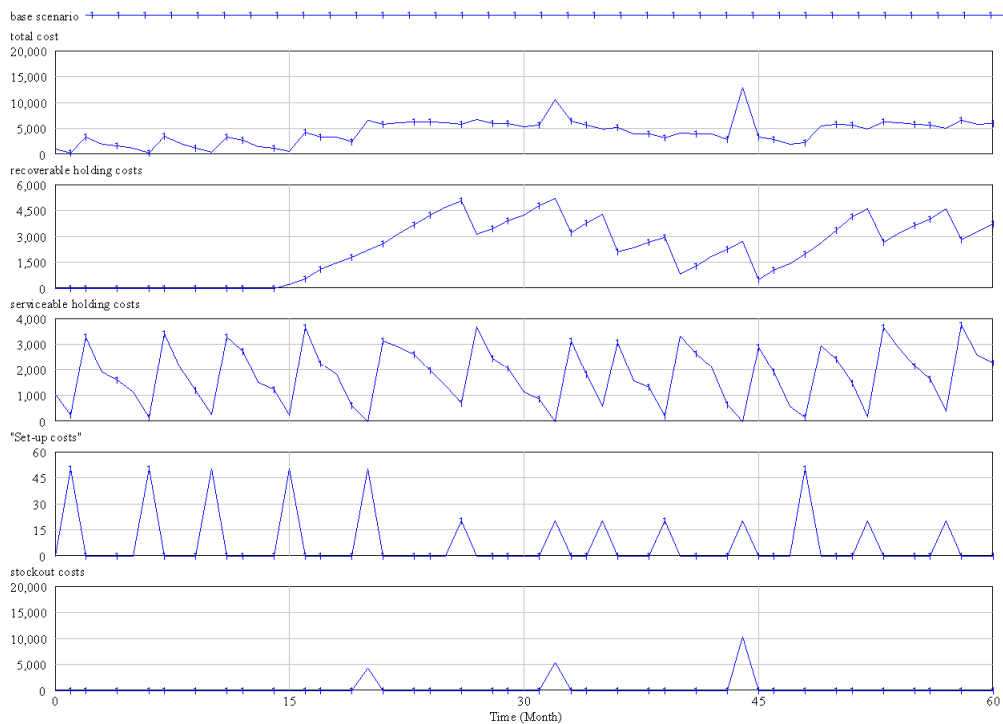

Figure 13: The costs trend for the base scenario

The evolution of the total cost shows a growing trend during the planning horizon. It is important to remember that the increase of the total cost does not cause a negative aspect in the model. Company costs could increase due to reverse logistics activities such as remanufacturing and disposal with a subsequent need to optimize the total costs (Inderfurth 2005). This analysis does not involve the profit margin of the inventory system but it focuses on the effects that the returns process and several involved parameters have on the average total inventory cost. Figure 13 shows a decreasing trend to the total cost for the time period between the months 30 ($5,342) and 45 ($3,370) which involves high remanufacturing activity as is shown by the reduction of recoverable inventory and the use of cheaper remanufacturing orders. This high remanufacturing activity could be associated with the reduction of the total cost, as the serviceable holding costs have a constant or rather growing trend during the planning horizon, particularly for the same time period, and stockout costs have two peaks during the same period.

Table 1: Parameter values used for returns process scenarios

Scenarios	residence time	SERVICE AGREEMENT WITH CUSTOMER	CUSTOMER BEHAVIOUR
base scenario	12	50%	2
Fast used products	2	20%, 40%, 60%, 80%, 100%	1, 2, 3
	12	20%, 40%, 60%, 80%, 100%	1, 2, 3
	18	20%, 40%, 60%, 80%, 100%	1, 2, 3
Slow used products	24	20%, 40%, 60%, 80%, 100%	1, 2, 3
	36	20%, 40%, 60%, 80%, 100%	1, 2, 3
	42	20%, 40%, 60%, 80%, 100%	1, 2, 3

Hence, the analysis focuses on the effect of the three parameters previously mentioned on the average of total inventory costs. The results refer to the effect of various levels of *RESIDENCE TIME*, *SERVICE AGREEMENT WITH CUSTOMER* and *CUSTOMER BAHAVIOUR*. Particularly the system was examined using 6 levels of residence time, 5 levels of service agreement and the 3 levels of customer behaviour. Table 1 lists the parameter values used for the analysis which involves a total of 90 scenarios.

The various scenarios are characterized by low and high *residence times* which are identified with *Fast used products* and *Slow used products* respectively. The choice of this table structure is due to the relationship between *residence time* and kind of products. While, with a reference to a kind of product, *SERVICE AGREEMENT WITH CUSTOMER* and *CUSTOMER BEHAVIOUR* are considered as the policies/incentives that companies use to have back used products and the customer tendency in returning them. The parameter values used to set the residence time are realistic as they can be associated with several remanufacturable products (Georgiadis, Vlachos and Tagaras, 2006). The assumed values for *SERVICE AGREEMENT WITH CUSTOMER* can represent a broad range of company policies and incentives types which develop a relationship between companies and customers in the returns process. In the same way, the different levels of *CUSTOMER BEHAVIOUR* are representative of a broad range of responsive aptitudes.

Figure 14 presents the evolution of the average total inventory cost for various simultaneously simulated levels of *residence time* and *SERVICE AGREEMENT WITH CUSTOMER*, referring to a *CUSTOMER BEHAVIOUR* equal to 3. The numerical results are presented in Table 2.

Table 2: Average total inventory cost for various combination of *RESIDENCE TIME* and *SERVICE AGREEMENT WITH CUSTOMER*, (CB3)

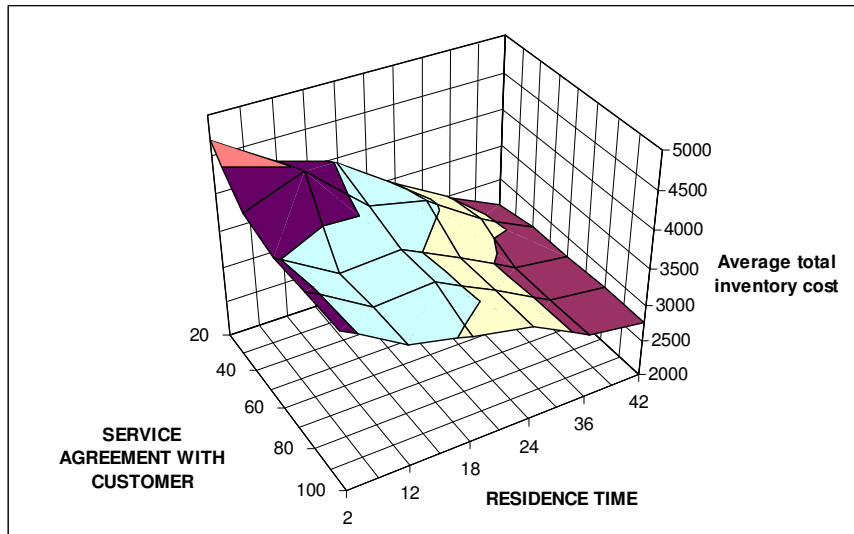| RESIDENCE TIME	2	12	18	24	36	42
SERVICE AGREEMENT WITH CUSTOMER						
20	4682.844	4201.623	3950.233	3427.938	2986.571	2635.332
40	4180.362	4466.277	3772.101	3606.984	3104.66	2717.271
60	4048.493	3588.229	3638.265	3245.864	2848.161	2747.953
80	4101.747	3632.09	3675.943	3276.057	2868.204	2762.135
100	4124.429	3650.807	3454.465	3288.989	2876.753	2768.202

Figure 14: The evolution of the average total inventory cost affected by *RESIDENCE TIME* and *SERVICE AGREEMENT WITH CUSTOMER*, (CB3)

The first observation shows a decrease of the average total inventory cost for high level of residence time. *Slow used products* have a reduced cyclic nature of return as the products remain with customers longer. In the model the reduced cyclic nature of return of a product is represented by the long time period between the product sale and its possible return.
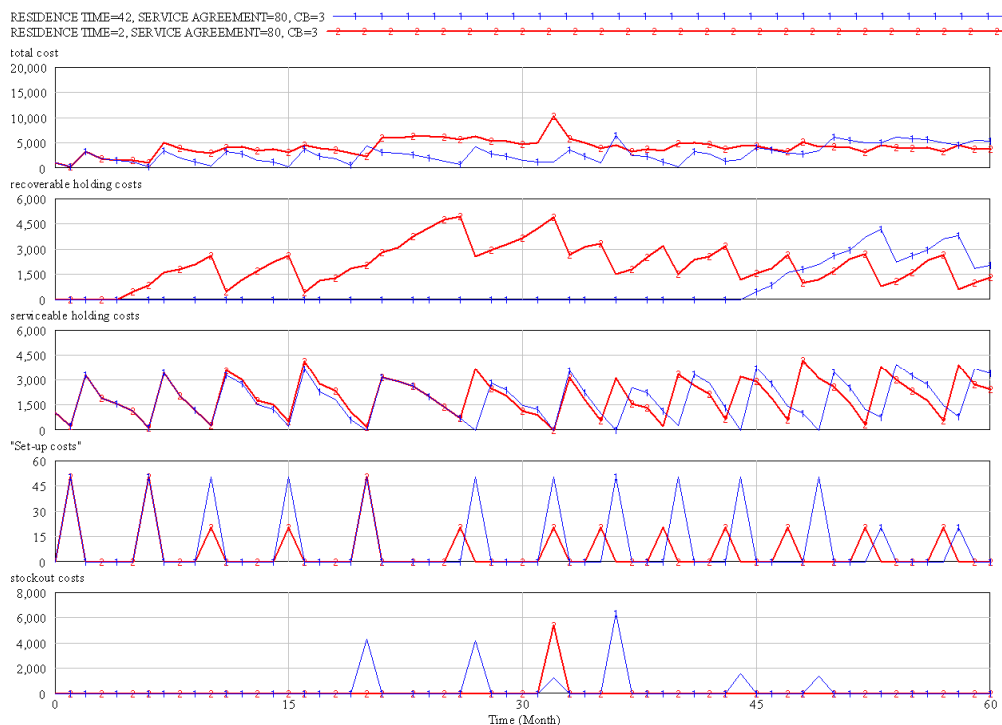

Figure 15: Evolution of the average total inventory cost for a *slow used product* and a *fast used product*

As is shown by recoverable holding costs in Figure 15, for a residence time equal to 42 months, a portion of products sold at time 0 of the planning horizon become

remanufacturable returns only after the long residence time. Then, during this time period they do not affect the recoverable inventory and its associated cost. In a different way, products with short resident time have a fast cyclic nature of return and they are quickly involved in recoverable inventory and remanufacturing activity. Therefore in the short period, s*low used products* have a reduced use of recoverable inventory and remanufacturing activity with a consequent reduction of the total inventory cost. Considering also that serviceable holding costs are independent of the remanufacturing or production of the product and consequently of the residence time, and that stockout cost are often special events, as Figure 15 shows.

This observation does not prove that *slow used products* are promising candidates for a profitable remanufacturing process. On the contrary, in the context of Closed Loop Supply Chain, examples of profitable remanufacturing process include f*ast used products* such as single use cameras (Kodak) and assemblies or sub assemblies of copiers/printers (Fuji Xerox). These kinds of products generate high levels of return and recoverable inventory with a subsequent increase in the total inventory costs. But, at the same time, cheaper remanufacturing activity is a substitute for more expensive production activity, as is shown by the set-up costs in Figure 15. As the structure of the model does not involve remanufacturing and production costs then it is not possible to make any conclusion regarding a profitable remanufacturing. However, several examples are given of products with low residence time or short life cycle and high returns rate for which high stock levels increase inventory costs. However, remanufacturing activity is in the long run economically profitable for reduced production costs such as purchasing and service costs (Flapper, Van Nunen and Van Wassenhove, 2005).
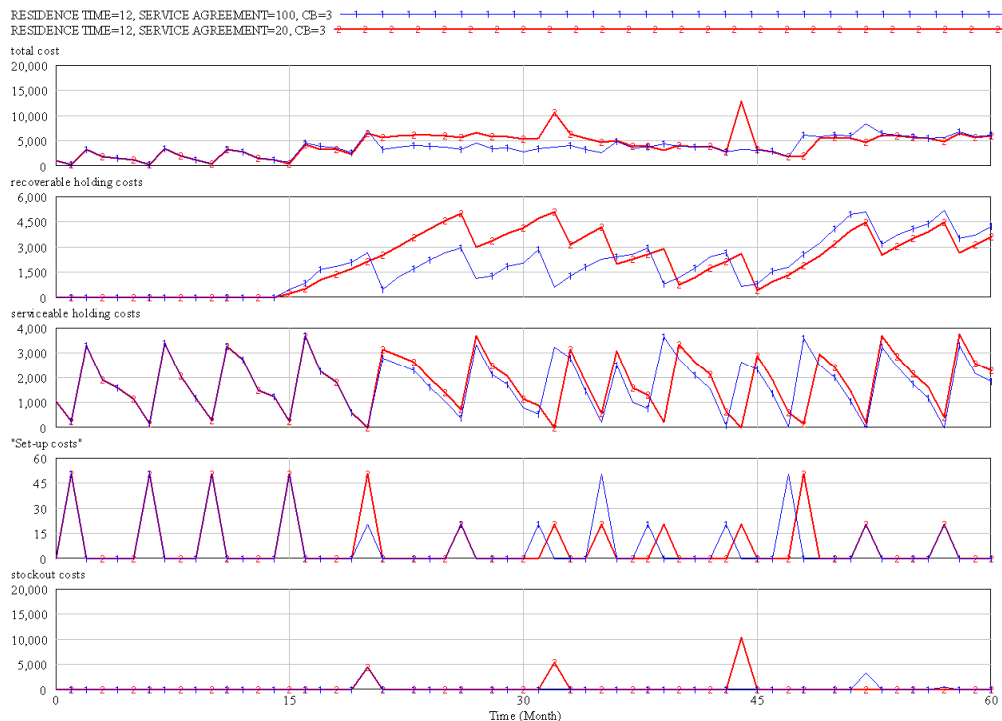

Figure 16: Evolution of the average total inventory cost for high and low *SERVICE AGREEMENT WITH CUSTOMER*

The second observation, through the scenarios simulation, reinforces the possibility that high returns rate can generate a profitable remanufacturability in closed loop supply chains. From Table 2 and Figure 14 it is possible to observe a decrease of the average total inventory cost for each level of residence time, except for the highest one, increasing the *SERVICE AGREEMENT WITH CUSTOMER* from 20% to 100%. The cost variation is not as significant as increasing the residence times. However it can prove efficiency in managing inventory in the remanufacturing process. High incentives for product recovery and consequently high returns rate and quantity of remanufacturable returns can increase the level of recoverable inventory which can be used to generate remanufacturing orders faster as a substitute for production. This reduces the average level of recoverable inventory and consequently the average total inventory cost, as Figure 16 shows in *recoverable holding costs*. Moreover, the use of more remanufacturing activity does not negatively affect the effectiveness of the system as is shown in Figure 16 where stockout quantity and costs are reduced for a higher returns rate.

Table 2 shows a higher reduction of the average total inventory cost, increasing the *SERVICE AGREEMENT WITH CUSTOMER* from 20% to 100%, for *fast used products* than *slow used products* for which an increase of cost characterizes the highest residence time (42 months). This difference of cost trend is due to the lower influence of the *slow used products* on recoverable holding costs and recoverable inventory as noticed in the first observation. In this case, the increase of the service agreement or incentives increases the quantity of recoverable inventory but only after a long residence time. This surplus of recoverable inventory does not affect remanufacturing as a substitute for production activity in the short period. Therefore, an increase of service agreement for product recovery could have a lower or negative effect on average total inventory cost for *slow used products* in a short time period. This is different for *fast used products* where an increase in incentives affects the quantity of recoverable inventory in a shorter time period which can then be used sooner in remanufacturing activity with subsequent benefits in recoverable inventory and production activity reduction. However, in the long term *slow used products* can be benefited from a percentage increase of the service agreement. Increasing the planning horizon from 60 to 120 months, the average total inventory cost for *slow used products* with residence time equal to 42 months decreases from $3,834 for 20% of *SERVICE AGREEMENT WITH CUSTOMER* to $3,601 for 100% of *SERVICE AGREEMENT WITH CUSTOMER*. Examples of closed loop supply chains for *slow used products* such as white goods are presented in literature (Flapper, Van Nunen and Van Wassenhove, 2005). The main drivers for the reverse logistic process of such products are Government legislations which include the responsibility of producers in recovery of their end of life products. However, incentives to the customer and several factors involved in the process are given in order to increase the returns rate for economic and environmental benefit such as low costs and reduced uncontrolled disposal.

Simulations, using the same values for the parameters *RESIDENCE TIME* and *SERVICE AGREEMENT WITH CUSTOMER* presented in Table 1, were examined setting CUSTOMER BEHAVIOUR equal to 2 and 1. Table 3 and Figure 17 show the evolution of the average total inventory cost for changes in *CUSTOMER BEHAVIOUR* and percentage of *SERVICE AGREEMENT WITH CUSTOMER,* with a *RESIDENCE TIME* equal to the base value of 12 months.

The reduction in the value of *CUSTOMER BEHAVIOUR* from 3 to 1 decreases the returns rate and consequently the average number of returns. This applies to every percentage of *SERVICE AGREEMENT WITH CUSTOMER* except for 100% for which *return index* and consequently the returns rate is independent of the customer behaviour. These simulation results can be realistic and representative as a lower response from customers to the company incentives for the recovery of used products in a closed loop supply chain process can reduce the quantity of returns. However, usually this should not occur for products for which companies maintain ownership such as products under leasing contracts or for products which companies are responsible for recovering due to environmental Government legislations.

Table 3: Average total inventory cost for various combination of *SERVICE AGREEMENT WITH CUSTOMER* and *CUSTOMER BEHAVIOUR*, (*RESIDENCE TIME* = 12)

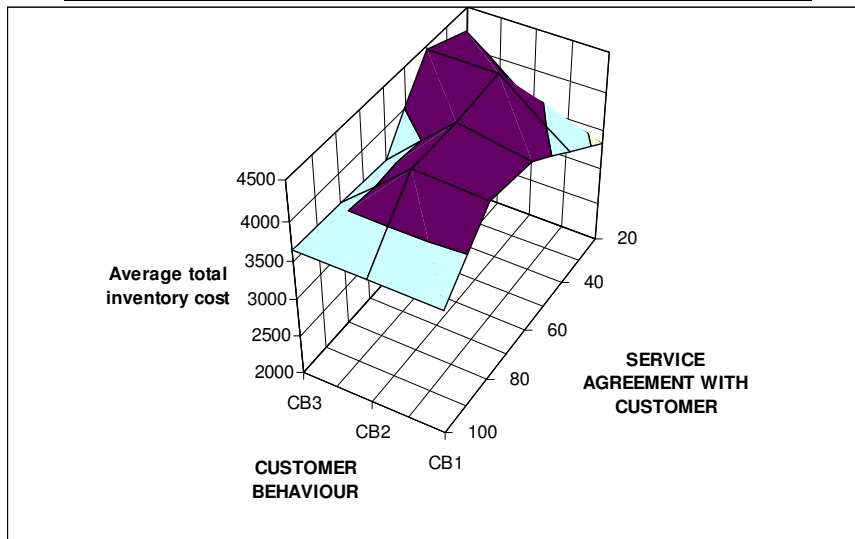| CUSTOMER BEHAVIOUR	CB3	CB2	CB1
SERVICE AGREEMENT WITH CUSTOMER			
20	4201.623	3534.054	3339.559
40	4466.277	4465.936	3779.627
60	3588.229	4390.815	4230.37
80	3632.09	4380.441	4338.692
100	3650.807	3650.807	3650.807

Figure 17: The evolution of the average total inventory cost affected by *CUSTOMER BEHAVIOUR* and *SERVICE AGREEMENT WITH CUSTOMER*, (*RESIDENCE TIME* = 12)

This reduction of returns quantity due to changes in customer behaviour has several consequences on the inventory system and its average total cost. From Table 3 and Figure 17 it is possible to observe that for higher percentages of *SERVICE AGREEMENT WITH CUSTOMER* such as 60% and 80% the average total inventory cost increases if the customer response (and returns rate) is lower. This is due to a lower level of recoverable returns in a shorter period. Higher levels of service agreement or incentives and at the same time higher response from customers to these incentives

increase the level of remanufacturable returns. Therefore, in a shorter period it is possible to use remanufacturing as a substitute to production activity with subsequent economic benefits through reduction of recoverable inventory and holding costs and through cheaper manufacturing processes. The same observation has been previously noted in Figure 16 with an increase of *SERVICE AGREEMENT WITH CUSTOMER*.

Differently way from Table 3 and Figure 17 it is possible to observe that for lower percentages of *SERVICE AGREEMENT WITH CUSTOMER* such as 20% and 40% the average total inventory cost decreases if the *CUSTOMER BEHAVIOUR* value decreases. In this case, as the top of Figure 18 shows, the low quantity of returns due to low incentives and low customer response leads to a low level of recoverable inventory which is almost always lower than the level of recoverable inventory for the higher *CUSTOMER BEHAVIOUR*. The latter involves more remanufacturing activity but not enough in order to have the lower recoverable inventory level. Therefore, in the case of low values for *CUSTOMER BEHAVIOUR* the level of recoverable inventory involves lower holding costs but at the same time lower remanufacturing activity. This observation could negatively affect companies involved in remanufacturing activity for closed loop supply chain process which require enough quantity of returns to increase remanufacturing as a substitute of production activity. However, the bottom of Figure 18 and the data in the right column of Table 3 show that in the case of low customer behaviour the increased percentage in the service agreement could not have the expected reduction in cost. As already mentioned, this is due to insufficient remanufacturing activity in order to reduce and lower recoverable holding costs.
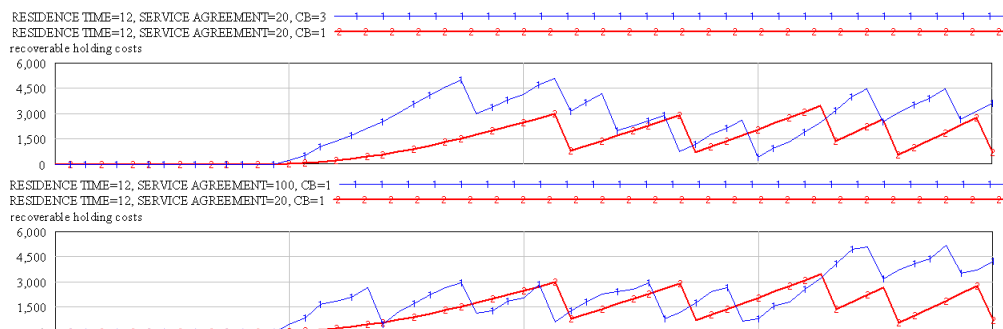

Figure 18: Evolution of the recoverable holding costs for high and low *CUSTOMER BEHAVIOUR* and increased *SERVICE AGREEMENT WITH CUSTOMER*

7.   Discussion

Remanufacturing activity in the closed loop supply chain process needs enough quantity of remanufacturable returns in order to set a manufacturing process where cheaper remanufacturing can be used as a substitute to production activity. This process leads to economic and environmental benefits in reducing more expensive production activity. Remanufacturing uses 85% less energy than production, reduces landfill, pollution and raw material usage (Gray and Charter, 2007). Moreover, the analysis shows that an increase in remanufacturing activity can optimize the inventory system and its cost through efficiency in recoverable inventory. *Slow used products* with a longer residence time present in the short period a reduced use of recoverable inventory due to their reduced cyclic nature of return and consequently lower inventory cost than f*ast used products*. However, in the short term this could negatively affect remanufacturing as a

substitute for production activity for shortage of remanufacturable returns. On the other hand f*ast used products* can be used in a shorter period and prompt remanufacturing activity which reduces the inventory cost through efficiency in recoverable inventory. A prompt remanufacturing activity depends on the recoverable inventory on hand which, as the analysis shows, is influenced by *SERVICE AGREEMENT WITH CUSTOMER* and *CUSTOMER BEHAVIOUR*. An increase of both parameters leads to a higher level of recoverable inventory on hand and consequently to the possibility of prompt remanufacturing activity.

However, uncertainty in returns flow, particularly on timing and quantity of returns, can influence the results of the previous analysis on the inventory system. Several companies manage the uncertainty in quantity of remanufacturable returns which are stored in the recoverable inventory without attempting to balance returns with demands but they prefer instead to dispose of excess inventories on a periodic basis (Guide 2000). In the same way, several authors use a planned disposal of recoverable inventory in their models and probabilistic returns quantity or all demands as returns (van der Laan, Dekker and Salomon, 1996; van der Laan and Salomon, 1997; Vlachos, Georgiadis and Iakovou, 2007). In our inventory model, planned disposal of recoverable inventory is not considered, which could add a new inventory cost and be more profitable, following the reverse logistics *preponement* concept (Blackburn et al. 2004), before the stage of inspection. However, uncertainty in timing and quantity of returns is specifically tackled through the use of parameters such as *RESIDENCE TIME*, *SERVICE AGREEMENT WITH CUSTOMER* and *CUSTOMER BEHAVIOUR*. Their relationships in the returns process provides a forecasted returns rate and a possible time of return for used products with different product characteristics and in different industries. The knowledge of the products residence time coupled with combinations of incentives in product recovery such as trade-in and leasing contracts can assist in forecasting the time and quantity of returns. Moreover incentives, particularly leasing contracts and changes in product design for easier disassembly and recovery of product/components, can result in a reduction of the residence time with subsequent benefits as those previously mentioned for f*ast used products*. For example, the introduction of leasing contracts or changes in product design, for which customers can easily disassembly and return used product/components, can help in fixing the residence time as well as reducing it. In the same way through such incentives, companies can influence customer behaviour in returning used products. Through deposit fees, free collection or repurchase of used products, fees paid at the return of used products and particularly appropriate product design, clear information/advertising about the reverse logistics activities and environmental responsibilities can assist in increasing customer behaviour towards the returns process.

7.1. MobileMuster and incentives to improve customer behaviour

MobileMuster is the official national recycling program of the mobile phone industry in Australia (KPMG 2008). It is supported by the Australian Mobile Telecommunications Association (AMTA) which represents the national body of the mobile telecommunications industry. The program is a free recycling project for mobile phone users with environmental and economical benefits through a solution which avoids landfill activity and recovers material from used mobile phones. Project managers were contacted in order to obtain data and information, not about the recycling program (which is not topic of this study), but the influence of incentives on customers to return

used products, customer behaviour and returns rate. These data were obtained from the annual report 2007-2008 of the organization (KPMG 2008). Several incentives and service agreements with customers, retailers and other reverse logistics actors such as local councils and recyclers have been developed in order to increase returns/collection rate and customer behaviour towards the return process. In particular, the focus is on free used product collection from customers. This is achieved by distributing reply paid recycling satchels available in selected mobile phones packs and establishing public collection points nationwide in retailers and Australian Post outlets. Other incentives include customer communications and environmental campaigns about the MobileMuster program published in catalogues, on websites, through direct marketing and television advertising presented by mobile manufacturers, service centres and retailers. These activities have obtained varying results. Table 4 shows the evolution of particular KPIs for the MobileMuster program from the years 2005 to 2008. It is interesting to notice that since 2005 the awareness of the recycling program, which can represent the consumer behaviour towards the reverse logistics program, has increased from 46% to 75% and at the same time collection and collection rates have increased. The latter two factors can be representative of the quantity of returns and the returns rate of used mobile phones. Therefore, the incentives have affected the customer behaviour towards the return process and consequently increased the returns rate and reduced the disposal to landfill rate.

Table 4: Evolution of KPI for the MobileMuster program

Key Performance Indicators (KPI)	2007/08	2006/07	2005/06
Mobile Phone Collection (tonnes)	97	78	42
Annual Collection Rate	18.9%	18%	15%
Disposal to Landfill Rate	4%	5%	9%
Awareness of Mobile Phone Recycling (Consumer Behaviour)	75%	69%	46%

7.2. Fuji Xerox and incentives to the return process

Fuji Xerox is a leading global corporation which has achieved success through a re-investment of its business for remanufacturing the components of its office equipment products (Benn and Dunphy, 2004). In Australia Fuji Xerox supplies and services digital printing equipment such as printers, fax machines and photocopiers. Fuji Xerox has a reputation for market leading research and development and provides quality colour and black and white printers for organizations of all sizes (Environment Protection Authority 2002; Fuji Xerox Australia Pty Limited 2007b). Product remanufacturing is an integral part of the business for this company. In 2006, 220,000 parts were remanufactured, saving Fuji Xerox in the order of $13 million in new part costs and creating revenue of $5.4 million in exports (Fuji Xerox Australia Pty Limited 2007a). Fuji Xerox Eco Manufacturing Centre in Zetland, Sydney, collects, disassembles and remanufactures used products so they can be reused through a process which uses less raw material and energy, reducing waste and disposal costs. The Centre remanufactures used parts and components, which are given the same guarantee as new products, for the Asia Pacific Region. According to the managers, the Eco Manufacturing Centre focuses and deals only with remanufacturing activity. For this

reason, predicting the quantity and timing of returns is essential in ensuring an efficient inventory and planning/scheduling of remanufacturing.

Another company advantage of remanufacturing activity is the constant evaluation and testing to which machines and components are subject. This leads to product improvements and extension of product life which provides the opportunity to remanufacture components several times (Fuji Xerox 2007). Sub assemblies and components are evaluated to identify reasons for failure or to determine the remaining life of the part, through diagnostics tools which compare the signature of a used part to that of a new part. Consequently, the latest generation of digital printers and copiers are built in modular format where all modules are capable of being remanufactured. In this way, remanufacturing activity can focus on modules with shorter residence time and easier remanufacturability rather than the whole machines. This process leads to faster recovery of returns from customers and reduces uncertainty in quality and cycle processing time of returned products with a subsequent reduction of operating expenses. Also, customer-driven returns and training for assembly/disassembly of the modules are services offered to the customers. These activities could lead to a more productive and cost effective system, through the guaranteed faster return of products/components which leads to more simplified remanufacture planning, scheduling and controlling.

Service agreements with customers is a company strategy employed by Fuji Xerox Australia in order to reduce uncertainty in quantity of returns in production and inventory planning/scheduling. In Australia this company is mainly a service provider, supporting this service with its own leasing finance company (Benn and Dunphy, 2004). Following this, the objective of Eco Manufacturing Plant is to produce high quality machines and to recover used components for remanufacturing. For this reason, most machines are leased to customers. This allows Fuji Xerox to keep track of the quantity and location of equipment and to have control over the remanufacturing process and returns rate (Fuji Xerox 2007).

Moreover, Fuji Xerox managers believe *full service agreement with customer* is an important strategy in the remanufacturing process. Fuji Xerox draws up a full service and maintenance agreement with customers whose response is usually to lease the products. The full service agreement has a number of targets including a marketing strategy to increase service levels to the customer, a returns process strategy to increase control of the quantity and timing of returns as well as the improvement of remanufacturing activity. The service is conducted by engineering teams that conduct break down maintenance, when customers find the product is not working satisfactorily, and preventive maintenance of the products. According to Fuji Xerox managers, data collection of these processes has led to continuous improvement of the basic product design and has resulted in a number of improvements. New machines are built for easier and faster disassembly, recovery and remanufacturing process. Durability of main assemblies and sub assemblies, which are usually measured based on a possible maximum number of copies to be completed, is designed so as to replace both components at the same time. In this way, during preventive maintenance it is possible to predict when it will be necessary to replace the assemblies for improved product performance and when it will be necessary to replace them all together.

8. Conclusion

This study and its observations allow us to identify future research needs and provide directions regarding the issue of uncertainty in quantity and timing of returns which

affects the returns rate in Close Loop Supply Chains, particularly for inventory control systems in the remanufacturing process.

A System Dynamics approach was used to model and simulate an inventory control system for a remanufacturing process in the context of Closed Loop Supply Chain. The *returns rate* was formulated using reverse logistics factors such as *residence time* (the tome period that products stay with customers) and *return index* (the quantity of possible returns from the customer demand). The *return index* was obtained by studying the relationship between the company incentives or service agreement developed to recover used products and the customer behaviour in returning them. The remanufacturing system was implemented using a pull inventory strategy.

By analysing total inventory costs, several observations were made regarding the effects of the *residence time* and changes in the level of company incentives and the resulting customer behaviour. The main observation is that companies involved in the remanufacturing process can obtain efficiency in managing inventory through shorter *residence time* and an increased level of company incentives and resultant customer behaviour. This leads to a higher level of recoverable inventory on hand and consequently the possibility of prompt remanufacturing as a substitute to production activity which in turn reduces the recoverable inventory level and its respective holding cost.

Moreover, company incentives for recovery of used products and customer behaviour have significant influences on the uncertainty of *returns rate* and ultimately on total inventory costs. Increasing company incentives or service agreement with customers which in turn increases customer behaviour in returning used products can improve control of the *returns rate*. We employed two company case studies (MobileMuster and Fuji Xerox Australia) to support our observation and findings. Specifically, Fuji Xerox Australia uses incentives such as changes in product characteristics and leasing contract to reduce the *residence time* and improve control on *returns rate*. However, further investigations, particularly surrounding the assumptions considered in order to simplify the analysis of the system, could be a topic for further research in the remanufacturing sector.

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