AN ADVANCED FRAMEWORK FOR INVENTORY MANAGEMENT IN REVERSE LOGISTICS

Francesco Longo

MSC-LES, Mechanical Department, University of Calabria, Via P. Bucci 44C, 87036 Rende, Italy

f.longo@unical.it

ABSTRACT

In the first part of the paper a survey of the most important models used for inventory management in reverse logistics is presented; models are classified according to the approach used for modeling demand and products returns. In the second part of the paper an advanced simulation framework based for inventory management in reverse logistics is proposed. The simulation framework is used to compare different inventory control policies with the aim of understanding their behavior (in terms of total costs) within a supply chain with products return.

Keywords: Reverse Logistics, Inventory Management, Modeling & Simulation

1. INTRODUCTION

Although it has been given increasing attention in the recent years, the origin of research on inventory control with returns can be dated back to the 70's and regards those systems in which customers return products after their leasing, renting or purchasing (Heyman, 1977). Over the years, researchers and practitioners have developed and proposed numerous planning and control methods to integrate the return flow of used products (products recovery) into the producers' material management (Fleischmann et al., 2002). In this context, it seems that the major difficulty is mainly due to the considerable uncertainty with respect to timing, quantity and quality of the return flow (that is often hard to influence by the producer) and to the integration of reverse logistics operations. Kleber et al. (2002) observes that new problems arise both along the supply chain and in each single supply chain node with the integration of reverse logistics and products recovery operations. Among others, the most important are collecting and disassembly of used products, production synchronization and remanufacturing, inventory management. It is worth saying that the meaning of products recovery is different according to the final recovery action: repair, refurbishing, remanufacturing, cannibalization and disposal (see Thierry et al., 1995). As shown later on, in this article the focus is on the multi-echelon inventory system in case of products returns considering two recovery options: products remanufacturing and products disposal.

In effect many authors have proposed quantitative models and approaches for studying single stage and multi-echelon inventory management system with products return. Fleischmann et al. (1997) propose a survey of these research studies by discussing the implications of the emerging reuse efforts, reviewing the mathematical models presented in the literature, and pointing out the areas in need of further research. However, the framework proposed by Fleischmann dates back to more than 10 years ago, therefore the time seems again right for an updated survey on the inventory management problem involving product returns. In this context, the objective of the paper is twofold. First, the article aims at providing the readers with a brief but systematic overview on the main inventory control models proposed (during the last decades) by researchers and practitioners working in this specific area. The authors subdivide the field according to the modeling approaches for demand and returns processes. A first major classification is made into deterministic and stochastic models. Moreover, stochastic models are then classified into periodic and continuous review models. Then, as second and most important objective, the authors present four stochastic models for a multi-echelon inventory management system (within a supply chain) that includes product returns. After presenting and discussing the models, the authors propose the supply chain conceptual model (integrating the multi-echelon inventory system) and implement the conceptual model within an advanced supply chain simulator. The simulator (called IMPRES, Inventory Management with Product REturns Simulator) is used to investigate and compare the behavior of the inventory control models in terms of supply chain costs (total supply chain costs, supply chain echelon costs, supply chain node costs). It is also shown that with respect to the state of the art the treatment proposed in this article considers more flexible and versatile inventory control models.

Before getting into the details of the study, in the sequel a brief overview of each section of the article is presented. Section 2 structures the state of the art on the inventory management with product returns; in particular section 2.1 is dedicated to deterministic models; section 2.2 presents stochastic models and classifies them into periodic and continuous review models. Then, section 3 deals with the supply chain conceptual model and the four stochastic inventory control models. Section 4 focuses on the IMPRES simulator and proposes an application example for comparing the behavior of the inventory control models in terms of supply chain costs (also discussing the potentials of the IMPRES simulator for investigating supply chain inventory management problems). Finally the last section reports conclusions, summarizes the scientific contribution of the work and the actual research activities still on going.

2. A SURVEY OF THE INVENTORY CONTROL MODELS WITH PRODUCTS RETURN

This section surveys the most relevant articles in the field of inventory management with product returns. The initial bibliographic search involving a huge number of articles were then reduced to about 50 articles based on content and quality. Such relevant articles are studied and considered in the following survey. Section 2.1 and section 2.2 are respectively dedicated to deterministic and stochastic models for single stage and multi-echelon inventory management system with product returns. Deterministic models mainly focus on extensions of Schrady's (1967) model (EOQ model applied to the case of products returns) and on the dynamic lot sizing problem for systems with product returns. Stochastic models are finally classified in periodic review and continuous review.

2.1. Inventory control models with products return: deterministic approach

Here research works dealing with deterministic models for inventory management are presented. These models are usually based on the assumption that demand and return quantities are known with certainty. A first research branch regards models dealing with stationary demand and return flows. The most considered inventory model is usually the Economic Order Quantity (EOQ). Schrady (1967) was the first to consider the EOQ inventory model in which a certain percentage of sold products (under constant demand) comes back, after a known period of time (constant return rate), to be repaired under the hypothesis of infinite production and recovery rates. Nahmias and Rivera (1979) extend Schrady's model by considering the case where the repair rate is finite rather than infinite. Other extensions to the model of Schrady (1967) are presented by Mabini et al. (1992) and Teunter (2001, 2004). Mabini et al. (1992) discuss an extension of Schrady's model to a multi-product inventories system where products share the same repair facility. Teunter (2001, 2004) also generalize Schrady's results. Teunter (2001) assumes infinite production and recovery rates and different holding cost for recoverable, recovered and manufactured products. Teunter (2004) assumes finite production and recovery rates. In both articles, Teunter derives a square-root formula for the optimal production and recovery lot-sizes for each of the two classes of policies: (M=1, R) and (M, R=1), where M manufacturing batches and R recovery batches succeed each other. The obtained policy is an approximation to the optimal and not the optimal one. However Teunter results are valid for finite and infinite production and recovery rates therefore has to be regarded as more general than those of Nahmias and Rivera (1979) and Koh et al. (2002).

Konstantaras and Papachristos (2004, 2006, 2007) extend Teunter in different cases, finding a solution for Teunter's model that leads to the optimal policy in both cases (M=1, R) and (M, R=1). Also Oh and Hwang (2006) and Chung et al. (2008) and Mitra (2009) extend Teunter (2001, 2004) even if they consider different systems, conditions and constraints. Oh and Hwang still deal with the single echelon case for a recycling system where a fixed fraction of the deterministic demand is returned and used as raw material. Chung et al. consider a multi-echelon inventory system with remanufacturing capability; Mitra consider a two echelon system with returns under more generalized conditions (the assumptions of non-existence or non-relevance of set-up and holding costs at different levels are relaxed).

Richter (1994, 1996a, b) and Richter and Dobos (1999) also consider EOQ models but they differ from Schrady's model because they consider the waste disposal option and the return rate is a variable parameters.

Richter's models are considered and extended by several authors: El Saadany and Jaber (2008) consider the costs associated with switching between production and recovery runs. Jaber and Rosen (2008) propose an extension of the model by proposing a parallel to physical systems and applying the first and second laws of thermodynamics to reduce system entropy. Finally, Jaber and El Saadany (2009) assume different demands for manufactured and remanufactured (repaired) products.

Another important branch of research studies deals with the dynamic lot sizing problem for systems with product returns. Richter and Sombrutzki (2000) propose an extension of Wagner and Whitin (1958) dynamic production planning and inventory control model to the case of reverse logistics. They assume that the number of returns is sufficient to satisfy all demands without delay, and therefore manufacturing is not considered. Richter and Weber (2001) extend the model proposed by Richter and Sombrutzki by considering the manufacturing option and variable manufacturing and remanufacturing costs. However Richter and Weber assume that the number of returns in the first period is at least as large as the total demand over the planning horizon, therefore the manufacturing option is not needed (it is used only for economic reasons). Richter and Gobsch (2003) apply the Richter and Sombrutzki model in a just in time environment.

Golany et al. (2001) extend Richter and Sombrutzki by relaxing restrictive assumptions on the number of returns and they also include the disposal option. Beltran and Krass (2002) relax the assumption on the number of returns but assume that returns can be directly used (no remanufacturing is needed).

Teunter et al. (2006) study the dynamic lot sizing problem by relaxing all the restrictive assumptions of the above models also including set-up costs.

2.2. Inventory control models with products return: stochastic approach

This section is dedicated to the inventory models that deal with demands and returns as stochastic processes. The survey is organized according to the traditional classification into periodic and continuous review models. Section 2.2.1 and section 2.2.2 respectively survey the periodic review models and the continuous review ones that have contributed to well establishing this field through the last four decades.

2.2.1. Periodic Review Models

Literature on periodic review models is abundant. These models aim at deriving optimal control policies over a finite planning horizon (Fleischmann et al., 1997).

The first contribution on stochastic periodic review model was first presented in Simpson (1978), but the research has not been continued. In terms of previous works, the model presented by Simpson is an extension of Veinott's (1966) model in which the dependent relationship between demand and returns is removed. In practice this dependency is rarely modelled because of the small effects and the modelling effort required to consider it (see Fleischmann 2000 for justification of the independence assumption and Kiesmüller and van der Laan 2001 for an additional cases in which returns depend on past demand).

After Simposon, Cohen et al. (1980) present a model where a fixed share of the products is returned after a fixed number of periods. Equations for the optimal policy are proposed, and myopic base stock approximation (that is shown to be optimal in the case of feedback delay is equal to one period) is developed. Inderfurth (1997) extends Cohen et al. model by relaxing the assumption of fixed feedback delay and addressing the problem of product recovery management. In this case, one single product is stocked to fulfill stochastic customers demand that generate, in turns, stochastic product returns (they consider the double options of manufacturing and disposal and assume fixed and different deterministic lead-times for both procurement and remanufacturing).

Kiesmüller and van der Laan 2003 provide the exact computation of the parameters that determine the optimal periodic policy proposed by Inderfuth (1997) and Simposon (1978) in the case of identical lead times. They also provide two different approximations in the case dynamics demand and returns (exact computation is time consuming). Mahadevan et al. (2003), Kiesmueller (2003), and Teunter et al. (2004) explore heuristic approaches for the case of non-identical lead times. Finally Ahiska and King (2009), extending Kiesmueller (2003), conducts an analysis to find optimal policy structure in the existence of fixed cost for manufacturing and/or remanufacturing in the context of periodic-review inventory control.

The above papers consider one products reuse option and one single stage inventory system. The following articles extend the treatment to the case of multiple reuse options and multi-echelon system. Inderfurth (2001) extends Inderfurth (1997) by firstly presenting a periodic review model for product recovery in stochastic remanufacturing systems with multiple reuse options, including a disposal option (still Inderfurth considers one single stage inventory system). DeCroix (2006) focuses on a multi-echelons inventory system but still considers one product reuse option. DeCroix uses the results by Simposon (1978) and by Inderfurth (1997). In effect the system proposed by DeCroix combines the key elements of two simpler systems: (i) the single stage remanufacturing system studied by Simpson and by and Inderfurth and (ii) the series system studied by Clark and Scarf (1960). In particular DeCroix investigates whether the optimal policy inherits the basic structural properties of the simpler systems. Note that DeCroix et al.(2005) already investigated the behaviour of a series system in which recovered products are returned directly to stock.

2.2.2. Continous Review Models

In these models the time axis is modeled continuously and the objective is to find optimal static control policies minimizing the long-run average costs per unit of time (Fleischmann et al., 1997).

A first continuous review model was proposed by Heyman (1977). In particular, the author proposes a model with independent demand and return occurrences (with generally distributed quantities and inter-occurrence times), trying to optimize the trade off between additional inventory holding costs and production costs savings and without considering fixed costs (an attempt to consider dependent demand and returns is made by Yuan and Cheung 1998). Muckstadt and Isaac (1981) propose a model similar to the Heyman's model but demand and returns are assumed to be unitary Poisson processes, the model applies to a situation with uncertain manufacturing lead times, finite remanufacturing capacity, nonzero procurement lead time and disposal option is not considered (they deal with both single and multi echelon models and fixed costs are not considered). Korugan and Gupta (1998) consider a model similar to Muckstadt and Isaac but they take into account the disposal option in a two-echelon inventory system with return flows.

Van der Laan et al. (1999) extend Muckstadt and Isaac by relaxing some restrictive assumptions (even if they do not consider disposal option). Van der Laan et al. consider the dependence between demand and returns, allow nonzero fixed remanufacturing costs, consider deterministic manufacturing and remanufacturing lead times and present exact procedures for evaluating the total expected costs.

Fleischmann et al. (2002) aim at presenting a comprehensive analysis of inventory management in a reuse context. The authors come down to the Muckstadt and Isaac model and provide a complete analysis deriving both an optimal control policy and an optimal control parameter values.

Ching et al. (2003) starting from the Heyman's and Muckstadt and Isaac's models (single-product inventory model with returns), they first include the replenishment costs and then consider two independent identical inventory systems where transhipment of returns from one inventory system to another is allowed.

Finally Mitra (2009) tries to relax most of the assumption of the previous models (such as non-existence or non-relevance of set-up and holding costs at different levels) and considers a two echelons system with returns under more generalized conditions.

All the above papers make the assumption that remanufacturing a return is, on the average, less costly than manufacturing a new product and disposing the return (in other words they made the assumption that remanufacturing is the primary source for satisfying demand). Aras et al. (2006) consider the situation in which returns quality is not always the same and consequently remanufacturing is not the primary source of satisfying demand. The authors establish that a simple average cost comparison is not a reliable basis for priority decisions in hybrid manufacturing and remanufacturing systems.

With respect to the state of the art, the treatment proposed in this article considers more flexible inventory control policies (i.e. respect to Heyman's and Muckstadt and Isaac's models). Different types of continuous and periodic review models (not only based on the s, Q model) are considered. The models are proposed and their behaviour (in terms of supply chain costs) is investigated within a multi echelon supply chain that includes the products return flow (with the double option of remanufacturing and disposal). To this end, an advanced supply chain simulator is developed, presented and used.

3. SUPPLY CHAIN CONCEPTUAL MODEL AND INVENTORY CONTROL POLICIES

Figure 1 shows the supply chain conceptual model: let be N the number of supply chain echelons and N_i the number of node in the *i-th* supply chain echelon. In addition to the direct flow of product, the supply chain also includes a reverse flow with two options: remanufacturing and disposal. Remanufactured products can join the direct flow in any of the N supply chain echelon. Note that upstream and downstream supply chain boundaries respectively are outside suppliers and customers.

The arrival process of customers demand at stores is Poisson; similarly the products return process to the remanufacturing areas is Poisson. Inventory management system within each supply chain node is based (as explained later on) on inventory control policies that consider both new products (shipped by upstream nodes) and remanufactured products. Stock-outs occurrences at each supply chain node can be completely backordered, partially backordered or registered as lost sales.

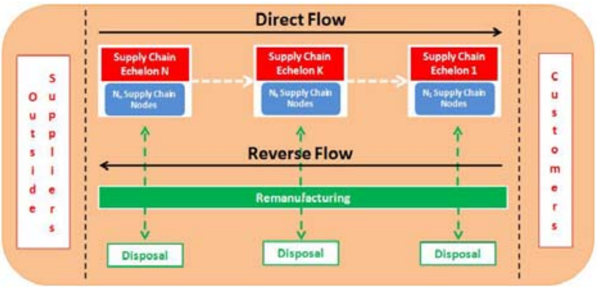

Figure 1: The supply chain conceptual model including the reverse flow of products

The inventory management system at each supply chain node has to answer to five different questions: (i) how often to review the stock status; (ii) when to order new products; (iii) quantity of new products; (iv) quantity of remanufactured products; (v) quantity of products to dispose.

Before getting into inventory policies details let us define the following notations. Note that, where not directly specified, the subscripts *i*, *j* and *k* respectively refer to the supply chain echelon *i*, to the echelon node *j* and to the product *k*.

- N, number of supply chain echelons;
- N_i, number of node in the *i-th* supply chain echelon;
- $D_{ijk}(t)$, customers' demand at period t;
- $RT_k(t)$, return at period t;
- LT_{ijk}, Lead Time (for a new product);
- LT_{rijk}, Lead Time (for a remanufactured product);
- $s_{ijk}(t)$, order point;
- $S_{ijk}(t)$, order-up-to-level;
- $SS_{ijk}(t)$, safety stock;
- h, safety stock factor (used for safety stock and order point evaluation);
- R_{ijk}, review period;
- r_{ijk}, inventory holding cost (for a new product);
- OC_{ijk}, fixed cost per order;
- v_{ijk}, unit value cost (for a new product);
- $B1_{ijk}$, fractional charge per unit short (used to evaluate shortage cost);
- $P1_{ijk}$, fractional part of stockouts backordered;
- $B2_{ijk}$, fractional charge per unit short (used to evaluate backorder costs);
- rc_{ik}, unit remanufacturing cost;
- rr_k, inventory holding cost (for a recoverable product);
- rv_k, unit value cost (for a remanufactured product);
- $P2_{ik}$, fractional part of disposed units;
- dc_{ik}, disposal cost;
- $DF_{ijk}(t)$, demand forecast at period t;
- $LTD_{ijk}(t)$, lead time demand;
- $\sigma_{ijk}(t)$, standard deviation of the lead time demand;
- $IP_{ijk}(t)$, inventory position;
- $OHI_{ijk}(t)$, on hand inventory;
- $OQ_{ijk}(t)$, on order quantity (new product);

- $OQ_{rijk}(t)$, on order quantity (remanufactured product);
- $BQ_{ijk}(t)$, back order quantity;
- $CQ_{ijk}(t)$, committed quantity;

Decisions about when to order new/remanufacturing products and the orders quantities are taken on the basis of the inventory position $IP_{ijk}(t)$ defined in equation (1).

$$IP_{ijk}(t) = OHI_{ij}(t) + OQ_{ijk}(t) + OQ_{rijk}(t) + \\ - BQ_{ijk}(t) - CQ_{ijk}(t) \quad (1)$$

The demand over the lead time (equation 2) is based on demand forecast in the time interval (t, t + LT) where LT is defined as:

$$LT = \begin{cases} LTD_{ijk}(t) \\ LTD_{rijk}(t) \\ Max\,(LTD_{ijk}(t), LTD_{rijk}(t)) \end{cases}$$

- The first case is for order placed only for new products
- The second case is for order placed only for remanufactured products
- The last case is order places for new products and remanufactured products

$$LTD_{ijk}(t) = \sum_{k=t+1}^{t+LT_{ij}} DF_{ijk}(k) \quad (2)$$

The Demand Forecast is evaluated by using the single exponential smoothing method. The operations of the four different inventory control policies are presented below.

3.1 Order-Point, Order-Quantity (s, Q) inventory control policy

This inventory control policy is based on continuous review; a fixed quantity Q_{ijk} is ordered when the inventory position, $IP_{ijk}(t)$ drops the order point $s_{ijk}(t)$.

In this case $s_{ijk}(t)$ and Q_{ijk} are determined according to equations for simultaneous determination of s and Q for faster moving products (adapted for Poisson Process), presented in chapter 8 of Silver et al. (1998), chapter 8.

3.2 Order-Point, Order-Up-to-Level (s, S) inventory control policy

As in the previous case the inventory is reviewed continuously and an order is placed whenever the inventory position, $IP_{ijk}(t)$, drops the order point $s_{ijk}(t)$. A variable quantity is ordered to raise $IP_{ijk}(t)$ to the order-up-to-level $S_{ijk}(t)$. The $s_{ijk}(t)$ is evaluated according to equation (3).

$$s_{ijk}(t) = LTD_{ijk}(t) + SS_{ijk}(t) \quad (3)$$

the safety stock:

$$SS_{ijk}(t) = h * \sigma_{ijk}(t) \quad (4)$$

The order-up-to-level:

$$SS_{ijk}(t) = s_{ijk}(t) + \frac{\overline{LTD_{ijk}(t)}}{\overline{LT}} \quad (5)$$

Where the second term of equation 5 is the ratio between the average lead time demand (considering lead time demand for new products and lead time demand for remanufactured products) and the average lead time (considering lead time for new products and lead time for manufactured products). Note that the authors already dealt with the definition of *SS* in a supply chain without products returns. See Longo and Mirabelli (2008), De Sensi et al. (2008) and Curcio and Longo (2009) for further information. Finally the quantity to be ordered is:

$$Q_{ijk} = S_{ijk}(t) - IP_{ijk}(t) \quad (6)$$

3.3 Periodic Review Order-Up-to-Level (R, S) inventory control policy

This inventory control policy is based on periodic review; every R units of time the inventory is checked and an order is placed that raises the inventory position, $IP_{ijk}(t)$, to the order-up-to-level $S_{ijk}(t)$, according to equation 5.

3.4 Periodic Review, Order-Point, Order-Up-to-Level (R, s, S) inventory control policy

As for the (R, S) inventory control policy, this policy is based on checking periodically the inventory. Every R units of time the inventory position $IP_{ijk}(t)$ is checked. If $IP_{ijk}(t)$ is below the order point $s_{ijk}(t)$ a variable quantity is ordered to raise the inventory position to the order-up-to-level $S_{ijk}(t)$, according to equation 6.

3.5 Supply Chain Total Costs definition

As already mentioned the main objective is to relax most of the assumption made in the stochastic models (both continuous and periodic review) and investigate the multi-echelon inventory system by comparing the behavior of the above inventory control policies in terms of total supply chain costs. This approach requires to specify inventory costs (including ordering costs, holding costs for new and remanufactured products, shortage costs, backordering costs), remanufacturing costs and disposal costs. Equation 7 evaluates the total expected annual cost for a generic product k at the echelon node j, supply chain echelon i:

$$
\begin{aligned}
TC_{ijk} &= OC_{ijk} m_{ijk} + v_{ijk} r_{ijk} \Delta T_{ijk} + (1 - P1_{ijk}) B1_{ijk} v_{ijk} n_{ijk} \\
&+ P1_{ijk} B2_{ijk} v_{ijk} n_{ijk} + rv_{ijk} rr_{ijk} \Delta T^{(r)}_{ijk} + \\
&+ (1 - P2_{ik}) rc_{ik} rn_{ik} + P2_{ik} dc_{ik} rn_{ik}
\end{aligned}
\qquad (7)
$$

where:

- ΔT_{ijk}, total time an product is held on the warehouse shelves (serviceable inventory);
- m_{ijk}, number of product orders over 1 year;
- n_{ijk}, number of unit short over 1 year;
- $\Delta T^{(r)}_{ijk}$, total time an product is held on the warehouse shelves (recoverable inventory);
- rn_{ik}, number of recoverable unit over 1 year, intended for remanufacturing process.

The total cost including all products types, inventory costs at all supply chain nodes and echelons, remanufacturing and disposal costs can be written as follows (equation 8)

$$
\begin{aligned}
TC &= \sum_i \sum_j \sum_k OC_{ijk} m_{ijk} + \sum_i \sum_j \sum_k v_{ijk} r_{ijk} \Delta T_{ijk} + \\
&\sum_i \sum_j \sum_k (1 - P1_{ijk}) B1_{ijk} v_{ijk} n_{ijk} + + \sum_i \sum_j \sum_k P1_{ijk} B2_{ijk} v_{ijk} n_{ijk} \\
&+ \sum_i \sum_j \sum_k rv_{ijk} rr_{ijk} \Delta T^{(r)}_{ijk} + \sum_i \sum_j \sum_k (1 - P2_{ik}) rc_{ik} rn_{ik} + \\
&\sum_i \sum_j \sum_k P2_{ik} dc_{ik} rn_{ik}
\end{aligned}
\qquad (8)
$$

Note that the treatment proposed in this article does not consider most of the common assumptions hold in most of the approaches proposed in literature. Specifically a multi-echelon inventory system with products returns (with the double options: remanufacturing and disposal) is considered and

- the remanufactured products can enter the normal flow of products at any stage of the supply chain;
- remanufactured products are good as new products and economically more convenient but the Lead Time of the remanufactured products is different from zero and different from the Lead Time of the new products.
- products disposal is allowed at any stage of the supply chain
- all the relevant costs are considered and included.

4. THE IMPRES SIMULATOR

In this section an application example, developed by using an advanced supply chain simulator (IMPRES, *Inventory Management with Product REturns Simulator*), is presented. The IMPRES simulator recreates the three echelons supply chain conceptual model above presented, the multi-stage inventory system with product returns (including the remanufacturing and disposal options) and the four different inventory control policies. The main aim of the application example is to investigate the multi-echelon inventory system by comparing the behavior of the above inventory control policies in terms of total supply chain costs. Figure 2 shows the supply chain considered in the application example.

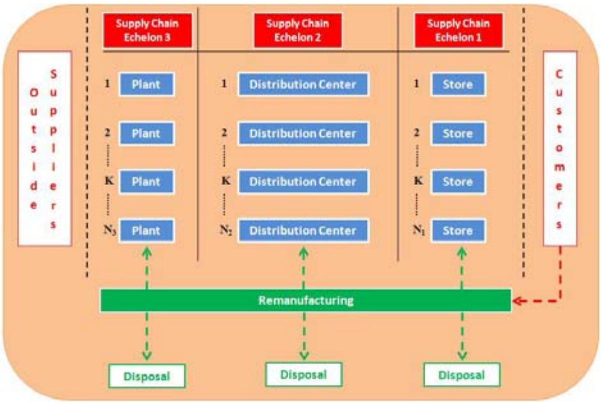

Figure 2: Supply Chain conceptual model considered in the application example

The use of Modeling & Simulation (M&S) is an important part of the proposed approach in order to investigate the multi-echelon inventory system and policies behavior. In effect, a wide range of factors usually affects the inventory management along the supply chain. The ways in which such factors interact and the stochastic nature of their evolution over the time increase the complexity of such system up to critical levels and the use of ad-hoc methodologies, techniques, applications and tools is the only way to tackle problems and succeed in identifying proper and optimal solutions (as already mentioned in the literature survey, analytical approaches mainly require restrictive assumptions).

Simulation has been widely recognized as the best and most suitable methodology for investigation and problem-solving in real-world complex systems (Bruzzone 2002; Bruzzone, 2004) in order to choose correctly, understand why, explore possibilities, diagnose problems, find optimal solutions, train personnel and managers, and transfer R&D results to real systems (Banks, 1998). Moreover, simulation has proved both in Industry and in Logistics its capability to recreate (with high level of accuracy) the intrinsic complexity of real-world systems allows to find out and test alternative solutions under multiple constraints and to monitor, at the same time, multiple performance measures, (Mosca et al., 1997; Giribone and Bruzzone, 1999, Bruzzone and Giribone, 1999, Bruzzone et al., 2007). In effect the author of this paper has a long experience in simulation models development in different areas including industrial plants (Longo et al., 2012), manufacturing systems design (Cimino et al. 2009; Longo and Mirabelli 2009), supply chains and Logistics (Bruzzone and Longo, 2010; Longo 2010) and complex systems training (Bruzzone and Longo, 2012). These considerations has led the author to develop the IMPRES simulator addressing the multi-echelon inventory management issue along the supply chain in the case of product returns.

The development of the simulator starts with a detailed analysis of the supply chain conceptual model According to the supply chain conceptual model a single network node is considered as store (ST), distribution center (DC) or plant (PL). A supply chain begins with one or more PLs and ends with one or more STs. STs usually satisfy market demand or demand from other STs, DCs satisfy STs demand or demand from others DCs and PLs satisfy DCs demand and demand from other PLs.

As concerns the inventory management, all the inventory control policies presented in section 3 are implemented within each supply chain node (ST, DC, PL). Obviously the inventory control policies take into account both the traditional forward-oriented product flow as well as the reverse product flow.

The figure 3 shows the IMPRES main frame (the figure depicts a supply chain example with three echelons including 4 plants, 3 Distribution Centers and 4 Stores) and the IMPRES Graphic User Interface (GUI). The GUI provides the user with many commands both for defining the supply chain configuration and for controlling the simulation execution. Number of products, simulation run length, start, stop and reset buttons and a Boolean control for the random number generator (to reproduce the same experiment conditions in correspondence of different operative scenarios) can be controlled and changed. Three different dialog windows can be activated by clicking on the three buttons *Stores*, *Distribution Centers* and *Plants* (see fig. 3). Thanks to these dialog windows, the user can set (in specific tables) the number of supply chain echelons, nodes position in the supply chain, the total number of network nodes and all the numerical values, input parameters and information needed for defining the supply chain configuration.

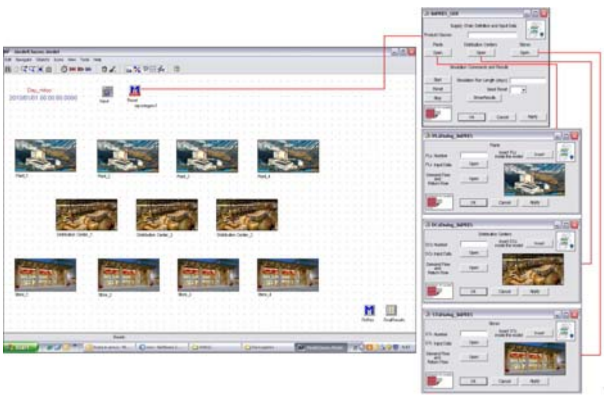

Figure 3: IMPRES main frame and Graphic User Interface

5. INVENTORY CONTROL POLICIES COMPARISON

Note that the high flexibility of the IMPRES simulator in terms of scenarios definition is one of the most important features for using it as a decision making tool. As mentioned above the IMPRES graphic user interface gives to the user the possibility to carry out a number of different what-if analysis by changing supply chain configuration and input parameters (i.e. inventory policies, demand forecast methods, demand intensity and variability, lead times, inter-arrival times, number of products, number of stores, distribution centers and plants, etc.). The application example proposed below aims at comparing the behavior (in terms of total supply chain costs) of the inventory control policies presented in section 3 in a three-echelons supply chain that includes 6 Plants, 1 Distribution Center, 10 Stores and 20 different products. The application example proposed has to be regarded as an advanced analysis devoted both to investigate inventory control policies behavior in case of products returns (with the double options of remanufacturing and disposal) and to test IMPRES potentials as tool to support supply chain managers decision making. Three different scenarios are considered:

- all the supply chain nodes use the (s, Q) policy;
- all the supply chain nodes use the (s, S) policy;
- all the supply chain nodes use the (R, S)

policy;

In effect a complete scenarios investigation requires at least a Design of Experiments (DOE) based on factorial experimental design for checking all inventory control policies combinations.

The figure 4 shows the total supply chain costs (in K€) in the three scenarios. Note that the best policy in terms of total cost is the (s, S) policy, the worst policy is the (R, S). When all the supply chain nodes use the (s, S) policy the total savings, compared to the use of (s, Q) and (R, S) policies, are respectively 1,415 K€ (about 8%) and 828 K€ (about 5%). It should be noted that the (s, S) policy as defined by authors (see equation 3 and 5) performs quite well than the (s, Q) policy.

Figure 4: Total Supply Chain Costs comparison

The figure 5 shows the total costs for each supply chain echelon (Plants, Distribution Centres and Stores) in correspondence of the three different inventory control policies. Once again the best policy is the (s, S). Note that on the whole supply chain the (s, Q) policy performs better than the (R, S). However when considering the single supply chain echelon the (s, Q) policy performs better than the (R, S) only in the Plants echelon and in the Distribution Centres echelon; it presents greater costs in the store echelon (and this is mostly due to a greater number of stock outs occurrences).

Finally figure 6 shows the different types of cost for the (s, S) policy. The graph reports all the costs defined in equations 7 and 8: ordering cost, carrying cost, shortage cost, backordering cost, carrying cost for remanufactured products, remanufacturing cost and disposal cost. Note that the most important costs are the inventory carrying cost for new products, the ordering cost, the inventory carrying cost for remanufactured products and the remanufacturing cost.

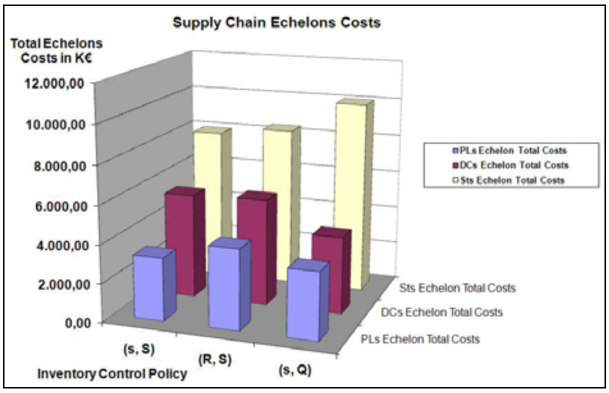

Figure 5: Supply chain Echelon Costs Comparison

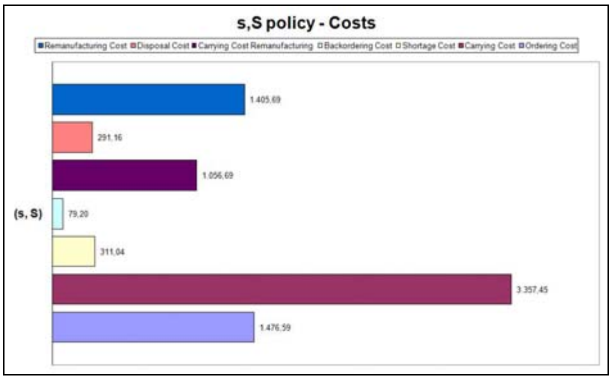

Figure 6: Cost types analysis for the (s, S) policy

Similar results have been obtained for each inventory control policies as well as for each supply chain node. In effect the IMPRES simulator is able to track individually each supply chain node as well as each products (new or remanufactured) within the whole supply chain.

6. CONCLUSIONS

The article addresses the very important issue of multi-echelon inventory management systems with product returns. The authors first propose a detailed state of the art overview on both deterministic and stochastic models proposed by researchers and scientists over the last decades. Then the authors deal directly with the inventory management with products return problem within the supply chain. It should be noted the research effort carried out by the authors in relaxing most of the common assumptions adopted in literature and presenting and investigating the behaviour of four different inventory control policies in terms of total supply chain costs. To this end the authors develop an advanced simulator, called IMPRES, that can be easily used as decision support tool. Analysis and results are also presented and show how the inventory control policies behave differently in terms of total supply chain costs as well as in terms of supply chain echelon costs.

Further research are still on going carrying out inventory parameters optimization by using Genetic Algorithms (with the aim of total costs minimization) and investigating inventory control policies behaviour with advanced DOE and ANOVA techniques.

REFERENCES

Ahiska, S.S., King, R.E., 2009. Inventory optimization in a one product recoverable manufacturing system. International Journal of Production Economics, In press.

Aras, N., Verter, V., Boyaci, T., 2006. Coordination and priority decisions in hybrid manufacturing/remanufacturing systems. Production & Operations Management, 15(4), 528–543.

Banks, J., 1998. Handbook of Simulation, John Wiley & Sons, New York, pp.3-30.

Bayindir, Z.P., Erkip, N., Gullu, R., 2003. A model to evaluate inventory costs in a remanufacturing environment. International Journal of Production Economics, 81, 597–607.

Beltran, J.L., Krass, D., 2002. Dynamic lot sizing with returning products and disposals. IIE Transactions, 34(5), 437-448.

Bruzzone A.G., Giribone P, Vio F. (1999). Genetic Algorithms and Simulation for Supporting Layout Re-Engineering of Automotive Component Production Facilities. International Journal of Flexible Automation And Integrated Manufacturing, vol. 7, p. 379-391, ISSN: 1064-6345

Bruzzone A.G. (2002). Introduction to the Special Issue on Simulation in Supply Chain Management. Simulation, vol. 78, p. 284-286, ISSN: 0037-5497

Bruzzone A.G. (2004). Preface to modeling and simulation methodologies for logistics and manufacturing optimization . Simulation, vol. 80, pp. 119-120, ISSN: 0037-5497, doi: 10.1177/0037549704045812

Bruzzone A.G., Briano A., Bocca E., Massei M. (2007). Evaluation of the impact of different human factor models on industrial and business processes". Simulation Modeling Practice and Theory, vol. 15, p. 199-218, ISSN: 1569-190X.

Bruzzone AG, Longo F (2010). An Advanced System for Supporting the Decision Process within Large-scale Retail Stores. Simulation, vol. 86, p. 742-762, ISSN: 0037-5497, doi: 10.1177/0037549709348801

Bruzzone A.G., Longo F., (2012). 3D Simulation as Training Tool in Container Terminals: the

TRAINPORTS Simulator. Journal Of Manufacturing Systems, ISSN: 0278-6125, doi: 10.1016/j.jmsy.2012.07.016
Buchanan, D.J., Abad, P.L., 1998. Optimal policy for a periodic review returnable inventory system. IIE Transactions, 30(11), 1049-1055.
Cimino A., Longo F., Mirabelli G., (2009). A multi measure-based methodology for the ergonomic effective design of manufacturing system workstations. International Journal of Industrial Ergonomics, vol. 39, p. 447-455, ISSN: 0169-8141, doi: 10.1016/j.ergon.2008.12.004
Ching, W.K., Yuen, W.O., Loh, A.W., 2003. An inventory model with returns and lateral transshipments. Journal of the Operational Research Society, 54(6), 636–641.
Chung, S.L., Wee, H.M., Yang, P.C., 2008. Optimal policy for a closed-loop supply chain inventory system with remanufacturing. Mathematical and Computer Modelling, 48(5-6), 867–881.
Clark, A. J., Scarf, H., 1960. Optimal policies for a multiechelon inventory problem. Management Science, 6, 475–490
Cohen, M.A., Nahmias, S., Pierskalla, W.P., 1980. A dynamic inventory system with recycling. Naval Research Logistics Quarterly, 27(2), 289-296.
Curcio, D, Longo, F., 2009. Inventory and Internal Logistics Management as Critical Factors Affecting the Supply Chain Performances. International Journal of Simulation & Process Modelling, vol. 5(4); p. 278-288.
De Sensi, G., Longo, F., Mirabelli, G., 2008. Inventory policies analysis under demand patterns and lead times constraints in a real supply chain. International Journal of Production Research, vol. 46(24); p. 6997-7016.
DeCroix, G., Jing-Sheng, S., Zipkin, P., 2005. A series system with returns: stationary analysis. Operations Research, 53(2), 350–362.
DeCroix, G.A., 2006. Optimal policy for a multiechelon inventory system with remanufacturing. Operations Research, 54(3), 532–543.
El Saadany, A.M.A. Jaber, M.Y., 2008. The EOQ repair and waste disposal model with switching costs. Computers & Industrial Engineering, 55(1), 219-233.
Fleischmann, M. 2000. Quantitative models for reverse logistics. Ph.D. dissertation, Erasmus University, Rotterdam, The Netherlands.
Fleischmann, M., Bloemhof-Ruwaard, J.M., Dekker, R., van der Laan, E., van Nunen, J. A.E.E., Van Wassenhove, L.N., 1997. Quantitative models for reverse logistics: A review. European Journal of Operational Research, 103(1), 1-17.
Fleischmann, M., Kuik, R., 2003. On optimal inventory control with independent stochastic product returns. European Journal of Operational Research, 151(1), 25-37.
Fleischmann, M., Kuik, R., Dekker, R., 2002. Controlling inventories with stochastic product returns: A basic model. European Journal of Operational Research, 138(1), 63-75.
Giribone P., Bruzzone A.G. (1999). Artificial Neural Networks as Adaptive Support for the Thermal Control of Industrial Buildings. International Journal of Power & Energy Systems, vol. 19, No.1, p. 75-78, ISSN: 1078-3466.
Golany, B., Yang, J. and Yu, G., Economic lot-sizing with remanufacturing options. IIE Trans., 2001, 33, 995–1003.
Heyman, D.P., 1977. Optimal disposal policies for a single-product inventory system with returns. Naval Research Logistics Quarterly, 24(3), 385-405.
Inderfurth, K., 1997. Simple optimal replenishment and disposal policies for a product recovery system with leadtimes. O R Spectrum, 19(2), 111-122.
Inderfurth, K., de Kok, A.G., Flapper, S.D.P., 2001. Product recovery in stochastic remanufacturing systems with multiple reuse options. European Journal of Operational Research, 133(1), 130-152.
Jaber, M.Y. Rosen, M.A., 2008. The economic order quantity repair and waste disposal model with entropy cost. European Journal of Operational Research, 188(1), 109-120
Jaber, M.Y. Saadany, A.M.A., 2009. The production, remanufacture and waste disposal model with lost sales. International Journal of Production Economics, 120(1), 115-124.
Kiesmuller, G.P., Minner, S., Kleber, R., 2000. Optimal control of a one product recovery system with backlogging. IMA Journal of Mathematics Applied in Business and Industry 11, 189–207.
Kiesmüller, G.P., Scherer, C.V., 2003. Computational issues in a stochastic finite horizon one product recovery inventory model. European Journal of Operational Research, 146(3), 553-579.
Kiesmüller, G.P., van der Laan, E.A., 2001. An inventory model with dependent product demands and returns. International Journal of Production Economics, 72(1), 73-87.
Kleber, R., Minner, S., Kiesmüller, G.P., 2002. A continuous time inventory model for a product recovery system with multiple options. International Journal of Production Economics, 79(2), 121-141.
Koh S.-G., Hwang H., Sohn K.-I., Ko C.-S., 2002. An optimal ordering and recovery policy for reusable products. Computers and Industrial Engineering, 43(1-2), 59-73.
Konstantaras, I. and Papachristos, S., 2004. Note: Lot-sizing for Inventory Systems with Product Recovery, Department of Mathematics, University of Ioannina, Ioannina, Technical Report No. 13.
Konstantaras, I. and Papachristos, S., 2006. Lot-sizing for a single-product recovery system with backordering. International Journal of Production Research, 44(10), 2031-2045.
Konstantaras, I. and Papachristos, S., 2007. Optimal policy and holding cost stability regions in a

periodic review inventory system with manufacturing and remanufacturing options. European Journal of Operational Research, 178(2), 433-448.
Korugan, A., Gupta, S. M., 1998. A Multi-Echelon Inventory System with Returns. Computer and Industrial Engineering, 35 (1-2), pp. 145 – 148.
Longo, F. and Mirabelli, G., 2008. An advanced supply chain management tool based on modeling and simulation. Computers & Industrial Engineering, 54(3), 570-588.
Longo F., Mirabelli G., (2009). Effective Design of an Assembly Line using Modeling & Simulation. Journal of Simulation, vol. 3, p. 50-60, ISSN: 1747-7778, doi: 10.1057/JOS.2008.18
Longo F (2010). Design and integration of the containers inspection activities in the container terminal operations. International Journal of Production Economics, vol. 125, p. 272-283, ISSN: 0925-5273, doi: 10.1016/j.ijpe.2010.01.026
Longo F, Massei M, Nicoletti L (2012). An application of modeling and simulation to support industrial plants design. International Journal of Modeling, Simulation, and Scientific Computing, vol. 3, p. 1240001-1-1240001-26, ISSN: 1793-9623, doi: 10.1142/S1793962312400016
Mabini, M.C., Pintelon, L.M., Gelders, L.F., 1992. EOQ type formulations for controlling repairable inventories. International Journal of Production Economics, 28(1), 21-33.
Mahadevan, B., Pyke, D.F., Fleischmann, M., 2003. Periodic review, push inventory policies for remanufacturing. European Journal of Operational Research, 151(3), 536-551.
Minner, S., Kleber, N., 2001. Optimal control of production and remanufacturing in a simple recovery model with linear cost functions. O R Spectrum, 23(1), 3-24.
Mitra, S., 2009. Analysis of a two-echelon inventory system with returns. Omega, 37(1), 106-115.
Mosca R., Giribone P., Bruzzone A.G., Orsoni A., Sadowski S. (1997). Evaluation and Analysis by Simulation of a Production Line Model Built with Back-Propagation Neural Networks. International Journal of Modelling & Simulation, vol. Vol.17, no.2, p. 72-77, ISSN: 0228-6203
Muckstadt, J.A., Isaac, M.H., 1981. An analysis of single product inventory systems with returns. Naval Research Logistics Quarterly, 28(2), 237-254.
Nahmias, S. Rivera, H., 1979. A deterministic model for a repairable product inventory system with a finite repair rate. International Journal of Production Research, 17(3), 215-221.
Nakashima, K., Arimitsu, H., Nose, T., Kuriyama, S., 2002. Analysis of a product recovery system. International Journal of Production Research, 40(15), 3849–3856.
Oh, Y.H., Hwang, H., 2006. Deterministic inventory model for recycling system. Journal of Intelligent Manufacturing, 17(4), 423-428.
Richter, K. Gobsch, B., 2003. The market-oriented dynamic product recovery model in the just-in-time framework. International Journal of Production Economics, 81-82 (1), 369–374.
Richter, K., 1994. An EOQ repair and waste disposal model. Pre-prints of the Eighth International Working Seminar on Production Economics, 3, 83-91.
Richter, K., 1996a. The EOQ repair and waste disposal model with variable setup numbers. European Journal of Operational Research, 96(2), 313-324.
Richter, K., 1996b. The extended EOQ repair and waste disposal model. International Journal of Production Economics, 45, 443–447.
Richter, K., Dobos, I., 1999. Analysis of the EOQ repair and waste disposal problem with integer setup numbers. International Journal of Production Economics, 59(1-3), 463-467.
Richter, K., Sombrutzki, M., 2000. Remanufacturing planning for the reverse Wagner/Whitin models. European Journal of Operational Research, 121(2), 304–315.
Richter, K., Weber, J., 2001. The reverse Wagner/Whitin model with variable manufacturing and remanufacturing cost. International Journal of Production Economics, 71(1-3), 447-456.
Roy, A., Maity, K., Kar, S., Maiti, M., 2009. A production–inventory model with remanufacturing for defective and usable products in fuzzy-environment. Computers and Industrial Engineering, 56(1), 87–96.
Schrady, D.A., 1967. A deterministic inventory model for repairable products. Naval Research Logistics Quarterly, 14(3), 391-398.
Silver, E. A., Pyke D. F., Peterson R., 1998. Inventory Management and Production Planning and Scheduling. Third Edition, Wiley.
Simpson, V.P., 1978. Optimum Solution Structure for a Repairable Inventory Problem. Operations Research, 26(2), 270-281.
Teunter, R.H., 2001. Economic Ordering Quantities for Recoverable Product Inventory Systems. Naval Research Logistics, 48(6), 484-495.
Teunter, R.H., Bayindir, Z.P., Heuvel, W.V.D., 2006. Dynamic lot sizing with product returns and remanufacturing. International Journal of Production Research, 44(20), 4377–4400.
Teunter, R.H., van der Laan, E., Vlachos, D., 2004. Inventory strategies for systems with fast remanufacturing. Journal of the Operational Research Society, 55(5), 475-484.
Thierry, M.C., Salomon, M., van Nunen, J., Van Wassenhove, L., 1995. Strategic issues in product recovery management. California Management Review 37 (2), 114-135.

Toktay, L.B., Wein, L.M., Zenios, S. A., 2000. Inventory management of remanufacturable products. Management Science, 46(11), 1412-1426.
Van der Laan, E., Salomon, M., Dekker, R., Van Wassenhove, L., 1999. Inventory control in hybrid systems with re manufacturing. Management Science, 45(5), 733-747.
Veinott, A.F. Jr., 1966. The Status of Mathematical Inventory Theory, Management Science 12, 745-777.
Wagner, H.W., Whitin, T.H., 1958. Dynamic version of the economic lot size model. Management Science 5, 89–96.
Yuan, X.-M., Cheung, K.L., 1998. Modeling returns of merchandise in an inventory system. O R Spectrum, 20(3), 147-154.

AUTHORS BIOGRAPHY

Francesco Longo received his Ph.D. in Mechanical Engineering from University of Calabria in January 2006. He is currently Assistant Professor at the Mechanical Department of University of Calabria and Director of the Modelling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES). He has published more than 120 papers on international conferences and journals. His research interests include Modeling & Simulation tools for training procedures in complex environment, supply chain management and security. He is Associate Editor of the "Simulation: Transaction of the society for Modeling & Simulation International". For the same journal he is Guest Editor of the special issue on Advances of Modeling & Simulation in Supply Chain and Industry. He is Guest Editor of the "International Journal of Simulation and Process Modelling", special issue on Industry and Supply Chain: Technical, Economic and Environmental Sustainability. He is Editor in Chief of the SCS M&S Magazine (Europe Area). Newsletter and he has served as General Chair and Program Chair for the most important international conferences in the simulation area. His e-mail address is: f.longo@unical.it