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Technical Paper

Efficient multi-objective optimization of supply chain with returned products

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ABSTRACT

Closed loop supply chain aims at integrating return products in the traditional supply chain processes. The return flows generate new uncertain elements (returns and leadtimes) and optimization of inventory control in this context is a complex issue. Inventory policies have to generate good performances (service level, cost) and be easy to implement in practice. A supply chain model based on simulation and multi-objective optimization is proposed to optimize control policies for multi-echelon supply chain with returned products. The method is tested on three inventory policies which correspond to different ways of making decision.

1. Introduction

A supply chain can be defined as a system consisting of a set of enterprises (or sites) interacting to route and process a product from a set of suppliers to a set of customers [1]. Supply chain design deals with localization of supply chain sites, allocation of flows between sites, capacity setting of the sites and flow control [2]. The configuration of a supply chain is the results of decision taking related to these problems. Decision makers have to select one configuration to achieve various goals related to customer satisfaction and minimization of a set of costs [3]. The problem is complex and the number of solution may be high. Thus, decision support tools are appropriate to search a solution or a set of solution. The work presented in this paper is placed in this framework.

Environment protection has become a major concern for all supply chain stakeholders. It leads to some evolutions in supply chain management. New objectives and constraints are taken into account and recovery and valorization activities for end-of-life products are performed. The new material and information flows from customers to producers integrated in supply chain form closed-loop supply chain (CLSC).

In a CLSC, the main valorization option consists in remanufacturing product or parts to be used as new products or parts [4]. This requires recovering products from customer zone to valorization sites. Supply chain sites with valorization sites need simultaneous management of decisions related to new product process (transport and/or manufacturing) and recovery process (transport and/or remanufacturing). Thus, new inventory control policies have to be implemented to operate the supply chain. These policies have to take into account different types of uncertainties related to new product supply (demands, leadtimes) and return products management (returns, leadtimes). An important part of supply chain costs are related to inventory which are mainly influenced by control policies.

The work presented in this paper is on optimization of inventory control policies in supply chain with return product flows. An efficient method is proposed to optimize any type of policies in this framework. Then three heuristic policies are presented and optimized with this method. It is a simulation model coupled with a multi objectives optimization evolutionary algorithm to optimize two performances: inventory cost and service level. In Section 2, a literature review on closed-loop supply chains and remanufacturing policies is presented. We described in Section 3 the problem of inventory optimization with return flow and remanufacturing process. Various inventory policies and model for CLSC are proposed in Section 4. A simulation model coupled with a multi-objective algorithm is proposed in Section 5 to optimize these policies. In

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Section 6, an application is proposed and conclusions are presented in Section 7.

2. Literature review

Many references are proposed in literature on supply chain design to support decisions on localization, allocation and capacity. Most of these works use mixed integer program to model and solve the problems, see [5] for instance. This approach has some drawbacks related to uncertainties management and connections with tactical problems like inventory control [6]. Some approach has been proposed to address these problems by using simulation models coupled with optimization methods: Ding et al. [7], Amodeo et al. [8] or Daniels and Rajendran [33]. Models proposed in these works do not address the problems of returned product flows and related control policies.

One option to handle returned products consists in remanufacturing these products or their components. It is a frequent option for automobile or photocopier products [9]. One or more supply chain sites (but not necessary all) can admit returned products and have to implement specific control policies to manage (1) quantity of new products to manufacture, (2) quantity of returned products to remanufacture, (3) quantity of returned products to dispose. When demands and returns are stochastics, optimal policy is too complex to be implemented in practice for periodic control [10], or continuous control [9], of the inventory system. Thus different heuristic rules have been proposed in literature. A review is presented in [32] where control policies are classified according to (i) structure of the inventory system (number and type of inventories), (ii) stochastic or deterministic data, and (iii) type of control (continuous or periodic). For systems with two inventories (serviceable and return), stochastic demands and returns and periodic control, several authors have studied a policy with three parameters, Inderfurth [10], Kiesmüller [11] and Van der Laan et al. [12]. This policy is also used in [13] with an environmental objective. This policy is simple to operate in practice and it is optimal when manufacturing and remanufacturing leadtimes are equals. In different framework, the return can be modeled as a function of the demand as in [14]. The authors derive a optimal continuous review policy for a two echelons systems.

After having established the structure of the policy, parameter values have to be set. Analytic methods, Inderfurth [10], Mahadevan et al. [15], Fleischmann et al. [16], are often too complex to be applied in practice. They are relevant for some structure of the cost function to be optimized but not for multi echelon supply chain. Some extensions are proposed for multiple echelon systems [17] and multiple valorization options [18]. DeCroix [19] proposes a analysis of the structure of the optimal policy for serial supply chain. It is showed that simple structure can be found only for particular conditions.

Supply chain with returned products and remanufacturing activities make a loop. They are called closed loop supply chain (CLSC). Initial works on CLSC aim at solving localization and allocation problem [20]. Specificities of return flows are pointed out and the problem is modeled with a mixed integer program. Uncertainty management is a major issue in reverse logistic which necessitates adapted methods. Chouinard et al. [21] model a localization and allocation problems with a stochastic mixed integer program which is solved with a sample average optimization method. Pishvaee et al. [22] also propose a network design model which is solved by a stochastic programming method to take into account various uncertainties. In [34], network flows are modeled with a queuing network which allow taking into account various uncertainties. Localization and allocation problems are then modeled as nonlinear mixed integer program which is solved with an evolutionary algorithm. Fuzzy modeling of uncertainties can also be used. Su and Lin [23] propose a one period lot sizing fuzzy model for recoverable manufacturing system. Abdallah et al. [24] propose to combine an EOQ (economic order quantity) model, to optimize the frequency and the quantities of procurements, with nonlinear mixed integer program, to set localization of the CLSC sites and allocation of flows between them. These works on CLSC do not address the problem of optimization of the control policy.

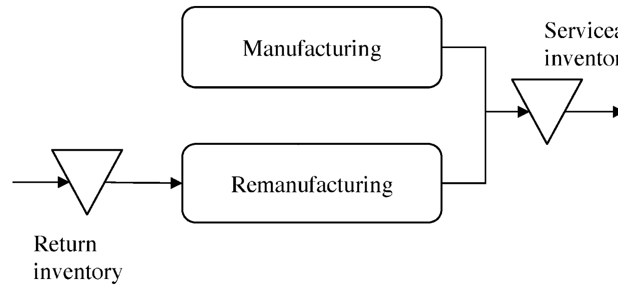

Fig. 1. Inventory system with returned products.

In the works reviewed, control policies for remanufacturing activities are developed for only one echelon inventory system and with only one objective. They are not connected with CLSC optimization. To fill this gap, an efficient method is proposed in this paper and it is implemented to optimize three heuristics policies. We also use the method to compare them. This approach consists in a simulation model combined with a multi-objectives evolutionary algorithm to optimize a multi echelon CLSC.

3. Problem statement

Return flows become more and more important in supply chain due to environmental pressures mainly [25]. Several options are possible to manage returned product and achieve environmental objectives [26]. Remanufacturing can be a profitable option when it allows procuring parts or materials of a product at a lower price. It requires however more complicated inventory control policy. Decision problem addressed in this paper concerns the optimization of inventory control policy in a CLSC. This problem in a supply chain without returned products is a traditional decision problem but difficult to solve [27]. It is made more difficult when return flows need to be taken into account.

The problem consists in optimizing inventory control policy in a multi echelon CLSC with stochastic demands, stochastic returns and one or more sites in the supply chain receiving returned products and performing recovery (remanufacturing, repairing, etc.) process. For these sites, two types of inventory have to be considered (Fig. 1):

- returned inventory: it corresponds to items (finished products, parts, raw material, etc.) which can be disposed or remanufactured,
- serviceable inventory: it is supplied by a manufacturing channel or by a remanufacturing channel and serviceable items are used to satisfy demands (the two channels are supposed to produce items with same quality).

Inventory control policies for this kind of system have to control two types of flows (new items and returned items) by considering the two types of inventory, Inderfurth [10]. The quantity of returned items at each period is not a decision variable and the returned items must be stored. At each period, three decisions are possible to supply serviceable inventory and limit return inventory: