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A hybrid two-stock inventory control model for a reverse supply chain

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ABSTRACT

This paper develops an inventory control model for a reverse supply chain with separate serviceable and remanufacturable inventory stock points. Return rate is expressed stochastically as a function of product demand. Variation in demand distribution during product life-cycle is modeled using a new order-up-to replenishment policy incorporating five maximum inventory levels corresponding to five product life cycle stages. A near optimum solution to this problem is sought using a hybrid solution method integrating a discrete event simulation with a meta-heuristic search method. Real data from an Australian case company is utilized to design test experiments for model validation and evaluation.

1. Introduction

Concerns about industrial implications on the natural environment have existed for decades. One alternative to benefit the environment is to design reverse supply chains to manage the backward flow of end-of life products destined for reuse, recycle or remanufacturing. Reverse practices in a recovery network can be environmentally beneficial from a product stewardship and extension of product life perspective (Fahimnia et al., 2013). Such practices may include recycling or remanufacturing of material that result in reduction of wastes and mitigation of resource depletion (Hu et al., 2002; El korchi and Millet, 2011). More producers are becoming responsible for the collection of their end-of-life products for recycling, reuse or proper disposal. In many cases however corporations commit themselves to reverse and recycling operations due the potential financial implications (Hsueh, 2011; Akçali and Çetinkaya, 2011; Ramírez, 2012; Benedito and Corominas, 2013).

The inclusion of reverse operations can add to the complexity of supply chain analysis, in particular inventory management decisions (Fleischmann and Kuik, 2003; Teunter et al., 2009). This is predominantly due to the additional uncertainties imposed by the recovery practices besides the regular uncertainties of a forward supply chain. The rate at which end-of-life products are returned as well as interruptions/variations in recycling or remanufacturing operations are amongst the most common uncertainty types (Esmaeilikia et al., in press). This well justifies the growing interest in development of stochastic inventory control models for reverse supply chains (van der Laan and Teunter, 2006; Karaer and Lee, 2007; Behret and

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Korugan, 2009). Another difficulty of managing reverse operations is the need to effectively coordinate manufacturing and remanufacturing activities at the operational planning level (Inderfurth and van der Laan, 2001; Ilgin and Gupta, 2010).

An excellent illustration of such challenging inventory policy decisions can be found in electronic industry. Short product life cycles due to rapid advances in technologies and tight product recovery regulations (e.g. Waste Electrical and Electronic Equipment Directive in Europe) are typical characteristics of electronic component manufacturing. In such environment, remanufacturing of returned products can be both economically viable and a contributor to corporates' ethical responsibility (Hsueh, 2011). Remanufacturing is an industrial process through which the worn out or obsolete components of used or damaged products are repaired or replaced for maximizing product useful life. Remanufactured products are in many cases considered as good as new and are hence used to satisfy the demand of new products. Examples include printer cartridges, car batteries and one-time-use cameras.

We focus our study on the development of a realistic two-stock inventory control model (i.e., separate serviceable and remanufacturable inventory stock points) for a reverse supply chain in which market demand and product return are both expressed stochastically in a way that return rate is a function of product demand. The serviceable inventory stock point is where the final product is stored and the remanufacturable stock point carries returned items suitable for remanufacturing. The objective of incorporating a remanufacturable stock point is to take advantage of low holding cost for storing inexpensive returned products and postponing the remanufacturing process to the time when needed. The dependency of return rate on product demand is particularly true when end-of-life, used and damaged products are directly returned to the original manufacturer. To model demand pattern during product life cycle, we introduce a new order-up-to replenishment policy with five maximum inventory levels corresponding to five product life cycle stages including introduction, growth, maturity, saturation and decline stages. A hybrid solution method is developed through integrating discrete event simulation with a meta-heuristic algorithm to find a near-optimum solution for the proposed inventory control problem. The performance of this solution method is then compared with that of the general-purpose OptQuest solver in a number of test experiments designed using real data from an Australian company involved in the provision of toner cartridges. Sensitivity analysis is finally performed to investigate the impacts of key factors on the cost benefits that can be obtained from the proposed two-stock model over a single-stock model.

This paper contributes to the literature of stochastic and periodic-review inventory modeling in the following ways. (1) This is the first study that explicitly considers the dependency of product return and market demand in presence of product life cycle in a two-stock system with backordering option. (2) This study characterized by the explicit modeling of demand and return dependency and a simple life cycle approach aims to investigate how the cost benefits of incorporating a second stock point can be dependent on product life cycle function. (3) We illustrate the difficulty of solving the proposed integer nonlinear stochastic model through the analysis of model specifications, i.e. a dimensionality analysis. (4) A novel Simulation-based Hybrid Variable Neighborhood Search is designed to solve the proposed model. Validation of the proposed solution method is completed comparing its performance against OptQuest solver in Arena.

2. Review of the existing literature

Reverse supply chain models can be classified into two groups including deterministic models (e.g. Richter and Dobos, 2004; Tang and Teunter, 2006; Atasu and Çetinkaya, 2006; Konstantaras and Papachristos, 2008; Teunter et al., 2009; Zanoni et al., 2012; Feng et al., 2014; Özceylan et al., 2014) and stochastic models. Stochastic models have been broadly discussed in two streams of continuous (e.g., Fleischmann et al., 2002; Aras et al., 2004; Behret and Korugan, 2009; Timmer et al., 2013) and periodically reviewed models (e.g., Vlachos and Dekker, 2003; Karaer and Lee, 2007; Zolfagharinia and Haughton, 2012; van Donselaar and Broekmeulen, 2013). We aim to make contributions to the stochastic and periodically reviewed modeling literature. In a typical periodic review inventory model with stochastic elements the goal is to minimize the expected inventory costs over a planning horizon by determining the related inventory and production policy decisions (see for example Inderfurth, 1997; Teunter and Vlachos, 2002; Mahadevan et al., 2003; Kiesmüller and Minner, 2003). The relatively recent review of Akçali and Çetinkaya (2011) classifies the published models based on the following characteristics: the number of stock points (single, double, or multiple stockpoints), the dependency of demand and return rates, length of planning horizon (finite or infinite), and lead time considerations.

Most of the published models assume the independency of demand and return rates (e.g. Heisig and Fleischmann, 2001; Teunter and Vlachos, 2002; Kiesmüller and Scherer, 2003; Fleischmann and Kuik, 2003; Karaer and Lee, 2007; Shi et al., 2011). There are two primary reasons for this assumption. First, the dependency of demand and return rates results in complex stochastic models requiring sophisticated solution methods to explore optimal or near-optimal solutions (Kim et al., 2013; Vercraene and Gayon, 2013). Second, while the dependency of product demand and return rate is a realistic assumption, accurate data on dependency patterns are not always easily accessible in real situations (de Brito and Dekker, 2003; Godichaud et al., 2012). This is the area our study aims to contribute to. We study a situation where used or rented/leased products are returned to the original manufacturer at the end of the product life cycle. The two important elements include the dependency of return rate to product demand and the need to adopt a life cycle approach.

Here we refer to some of the studies that we recognize as most related to our work. Kiesmüller and van der Laan (2001) studied a single-stock model in which the return rate is a function of product demand. A Markov-chain approach was used to determine the optimal order-up-to policy with respect to total average relevant cost for a finite planning horizon.