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Coordinated dispatching and acquisition fee decisions for a collection center in a reverse supply chain

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ABSTRACT

Collection centers play an important role for sustainable development in closed-loop supply chains by managing the collection activities of end-of-life (EOL) products and presenting them back to the economy. In this study, we focus on a collection center which collects EOL products that are composed of multiple components, disassembles the collected products, checks the quality of their components and sends the reusable parts to a remanufacturer at a certain price. The collection center needs to decide when to dispatch the collected products to the remanufacturer as well as the optimal acquisition fee in order to collect the right amount of EOL products from the end users and maximize its profit. We develop a dynamic programming model to maximize the long-run average profit of the collection center per unit time and analyze the optimal dispatching and acquisition fee decisions. We analyze quantity-based and time-based dispatching heuristics, which are widely used in practice, and compare their performances with the optimal dispatching decisions. We also compare static and dynamic acquisition fee models. We finally present a sensitivity analysis in order to analyze the effects of the parameters in our model. Computational results allow us to observe important managerial insights in this system regarding the optimal decisions depending on system parameters.

1. Introduction

The concept of closed-loop supply chains, which refers to the integration of forward and reverse supply chain activities, is one of the practices considered to improve the sustainability of supply chains (Banasik, Kanellopoulos, Claassen, Bloemhof-Ruwaard, & van der Vorst, 2017). Initially, the growing attention on closed-loop supply chain issues originated with public awareness. Then governmental legislation forced producers to take care of their end-of-life (EOL) products (Govindan, Soleimani, & Kannan, 2015). As stated by Savaskan, Bhattacharya, and Wassenhove (2004), the importance of the environmental performance of products and processes for sustainable manufacturing and service operations is increasingly being recognized. As a part of closed-loop supply chains (CLSC), reverse supply chains focus on taking back products from customers and recovering added value by reusing the entire product, and/or some of its modules, components, and parts (Guide & Van Wassenhove, 2009). Recently, product and material recovery has received growing attention throughout the world, with its three main motivators that include governmental legislations, economic value to be recovered and environmental concerns (Suyabatmaz, Altekin, & Sahin, 2014). Collection centers are one of the most important actors in these product recovery systems and they play a significant role in sustainable development. They deal with activities such as acquisition of EOL products from end users, reverse logistics, product disposition and dispatching of the products to the remanufacturing/repair facilities or disposal sites. Interested readers may refer to Guide and Van Wassenhove (2009), Souza (2013), Govindan et al. (2015) and Diallo, Venkatadri, Khatab, and Bhakthavatchalam (2017) for comprehensive reviews about the latest developments in various aspects of closed-loop supply chains.

In this study, we focus on collection, disassembly, warehousing and dispatching processes of a collection center that acquires EOL products from end users and sells them to remanufacturing facilities. As stated in the literature (e.g. Bakal & Akcali, 2006; Karakayali, Emir-Farinas, & Akcali, 2007; Zheng, Yang, Yang, & Zhang, 2017), the amount of collected products depends on the acquisition fee offered to the end users as an incentive to return their products. Thus, the collection center first needs to decide on the acquisition fee in order to collect the right amount of EOL products from the end users. Since the main product is composed of many different components, the collection center then disassembles the collected products in order to extract the reusable components. Each component has a different value and some of the components might be more likely to be reusable than the others. After the disassembly and quality control of the components, reusable

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components are stored until their dispatching time to the remanufacturer. The collection center needs to decide when to dispatch the reusable components. If the components are dispatched too frequently, there will be a high dispatching and transportation cost and if they wait too long at the collection center warehouse, there will be a high holding cost. Since there are many components with different values and different characteristics, determination of the optimal dispatching decision of these components in a coordinated manner can become very complex.

There are various studies in literature, which focus on different aspects of the collection process. For example, Reimer, Sodhi, and Jayaraman (2006) examine the issue of determining configurations for trucks that are involved in the collection of recyclables. Hong and Yeh (2012), Hong, Wang, Wang, and Zhang (2013), Chuang, Wang, and Zhao (2014) and Shi, Nie, Qu, Chu, and Sculli (2015) focus on the collection channel alternatives and compare various alternatives such as retailer collection, third party collection and manufacturer collection in different problem settings. Tagaras and Zikopoulos (2008) and Gu and Tagaras (2014) focus on the sorting issue and study various sorting alternatives such as no sorting, sorting at manufacturer, sorting at collection center. Zikopoulos and Tagaras (2015) examine simultaneously the issues of multiple collection sites, uncertain quality and inaccurate classification of returns in reverse supply chains. Paredes-Belmar, Bronfman, Marianov, and Latorre-Núñez (2017) propose a new approach to solve the problem of hazardous waste collection in a transportation network. Paydar, Babaveisi, and Safaei (2017) propose a mixed-integer linear programming model for a closed-loop supply chain of used engine oil with the objectives of maximizing profit and minimizing the risk of the collection.

Some of the papers in the literature deal with collection systems in a coordinated or uncoordinated manner. For instance, Hong, Xu, Du, and Wang (2015) propose Stackelberg game models for coordinated advertising, pricing and collection decisions. Mobasher, Ekici, and Özener (2015) focus on coordinated collection and appointment scheduling operations at the blood donation sites by considering processing time requirement of donated blood units for platelet production. Zheng et al. (2017) focus on a reverse supply chain consisting of a collector and a remanufacturer. They propose models to cope with pricing, collecting and contract design decisions. Habibi, Battaïa, Cung, and Dolgui (2017a) propose an optimization model to optimize the collection-disassembly problem in a coordinated manner. Then, Habibi, Battaïa, Cung, and Dolgui (2017b) focus on the same problem and propose a two-phase iterative heuristic to address large size instances efficiently. Hong, Govindan, Xu, and Du (2017) focus on quantity, collection and technology licensing decisions. They investigate two licensing patterns, namely fixed fee versus royalty. Han, Wu, Yang, and Shang (2017) focus on collection channel and production decisions under various remanufacturing disruption cases. Liu, Wang, Xu, Hong, and Govindan (2017) examine the influence of competition intensity on pricing, collection effort and reverse channel choice decisions.

There are also various studies in literature considering dispatching and shipment consolidation in forward supply chains under random demand. Bookbinder and Higginson (2002) evaluate the performance of several shipment consolidation practices in forward supply chains. Cetinkaya and Lee (2000) develop a model for this problem to compute the optimal replenishment quantity and dispatch frequency. Axsater (2001) provides a simple procedure to solve the exact model in Cetinkaya and Lee (2000). Chen, Wang, and Xu (2005), Cetinkaya, Mutlu, and Lee (2006) and Cetinkaya, Tekin, and Lee (2008) extend the analysis of this system under different settings considering time-based, quantity-based and hybrid shipment policies. Mutlu and Cetinkaya (2010) consider common carriage, rather than a private fleet of vehicles in the analysis of the model of Cetinkaya and Lee (2000). Cetinkaya and Bookbinder (2003) and Mutlu, Bookbinder, and Cetinkaya (2010) determine the optimal solutions for time-based, quantity-based and hybrid policies with private or common carriage opportunities and compare the performances of the three policies analytically.

Zaarour, Melachrinoudis, Solomon, and Min (2014) analyze a similar system to the one analyzed in this paper and they state that their study is one of the first to develop a mathematical model that can determine the optimal collection period at an initial collection point before transshipping the returned products to a centralized return center. However, different from our study, they assume deterministic returns and they only analyze a time-based policy in order to determine the shipment periods for a single product. They also assume that all collected products are reusable and checking the reusability of returned items is out of scope of their paper.

Our study differs from the studies in the literature in various aspects. Firstly, to the best of our knowledge, this is the first study in literature which analyzes the optimal dispatching policy for collection centers that collect end-of-life products composed of multiple reusable components with different characteristics (i.e. different values, different holding costs and different reusability probabilities). Secondly, we analyze quantity-based and time-based dispatching heuristics, which are widely used in practice, and compare their performances with the optimal dispatching decisions. In addition, in this study, acquisition fee decision is integrated with time-based, quantity-based and optimal dispatching policies. We determine the optimal dispatching and acquisition fee decisions in a coordinated manner and also compare static and dynamic pricing models for the acquisition fee decisions. All these policies as well as static and dynamic acquisition fee decisions are studied in a setting including nonlinear transportation costs, random arrival rates and batch sizes, as well as random quality levels of EOL products with different reusability probabilities of components.

The rest of the paper is organized as follows. In the next section, the scope of study and the problem are introduced with all details, and some basic definitions related to the problem are given. Then, the models for different cases are presented in Sections 3,4 and 5. Computational results are discussed in Section 6. Finally, conclusion and some future work suggestions are given in Section 7.

2. Problem definition and model

We consider a collection center which collects an EOL product composed of two main components, component 1 and component 2. The products are brought to the collection center by the end users in exchange for an acquisition fee per product, denoted as c_p. We assume random batch arrivals, such that the time between the arrivals of end users are assumed to be exponentially distributed with rate λ and each arriving end user brings a random amount of EOL products. Upon arrival, all products are disassembled and sent to a quality control area. In that area, basic quality control is made with a fixed quality control cost, denoted as c_q, and the company determines the reusability of component 1 and component 2. If they are reusable, the products are sent to the warehouse of the collection center to be stored until the next dispatching time. If not, they are sent to landfill. When the reusable components are dispatched to the remanufacturer, a revenue is obtained based on the amount of components shipped to the remanufacturer, where r_1 denotes the revenue per unit of component 1 and r_2 denotes the revenue per unit of component 2. We assume that the demand for reusable components is unlimited such that all the reusable components can be sold to the remanufacturer. The system is illustrated in Fig. 1.

We present the notation used for parameters and decisions variables in our models in Table 1.

It is seen in Table 1 that an EOL product includes reusable component 1 and component 2 with probabilities p_1 and p_2, that are assumed to be independent from each other. In addition, the batch size of an arrival is k with probability q_k, and m denotes the maximum number of products in a batch. Since a product is composed of two main components, let us define a new probability function $w_{i,j}$ such that $w_{i,j}$ denotes the probability that exactly i reusable component 1 and j reusable