European Journal of Operational Research 246 (2015) 435–449

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

Reverse supply chains: Effects of collection network and returns classification on profitability

Christos Zikopoulos [a,*], George Tagaras [b]

[a] Department of Economics, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece
[b] Department of Mechanical Engineering, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece

ARTICLE INFO

Article history:
Received 28 July 2014
Accepted 30 April 2015
Available online 9 May 2015

Keywords:
Multiple suppliers
Random yield
Location of sorting
Returns classification errors
Value of quality information

ABSTRACT

Used products collected for value recovery are characterized by higher uncertainty regarding their quality condition compared to raw materials used in forward supply chains. Because of the need for timely information regarding their quality, a common business practice is to establish procedures for the classification of used products (returns), which is not always error-free. The existence of a multitude of sites where used products can be collected, further increases the complexity of reverse supply chain design and management. In this paper we formulate the objective function for a reverse supply chain with multiple collection sites and the possibility of returns sorting, assuming general distributions of demand and returns quality in a single-period context. We derive conditions for the determination of the optimal acquisition and remanufacturing lot-sizing decisions under alternative locations of the unreliable classification/sorting operation. We provide closed-form expressions for the selection of the optimal sorting location in the special case of identical collection sites and guidelines for tackling the decision-making problem in the general case. Furthermore, we examine analytically the effect of the cost and accuracy of the classification procedure on the profitability of the alternative supply chain configurations. Our analysis, which is accompanied by a brief numerical investigation, offers insights regarding the impact of yield variability, number of collection sites, and location and characteristics of the returns classification operation both on the acquisition decisions and on the profitability of the reverse supply chain.

1. Introduction

Despite existing similarities, the differences between conventional (forward) and reverse supply chains (RSC) are numerous and generate a number of new research needs in the area of supply chain management. For example, contrary to typical forward supply chains where the number of suppliers for a specific raw material or component is usually small, collection of returns in RSC usually requires an extensive network of collection points. Product complexity is also higher in RSC, since returns consist of final products instead of simpler subassemblies or raw materials. Product quality is another complicating factor in RSC management because quality uncertainty is much higher in used products than in new ones.

Timely quality assessment is important in RSC because it can prevent waste of resources on practically useless items. In the RSC literature, there is a plethora of contributions on the assessment of the value of information on returns quality considering a diversity of industrial applications, such as Bosch (Guide, Souza, Van Wassenhove, & Blackburn, 2006), CertiCell (Galbreth & Blackburn, 2010a), automotive industry "similar to GreenLeaf LLC" (Bakal & Akcali, 2006), Hewlett-Packard (HP; Guide, Muyldermans, & Van Wassenhove, 2005) and Pitney-Bows (Ferguson, Guide, Koca, & Souza, 2009). As a result of the well-established value of quality information, the development of fast procedures for the classification of returned products according to their remaining value is a common business practice. However, since sometimes it is important to adopt sorting procedures characterized by low operational cost, firms often have to compromise classification accuracy.

Considering a large number of collection locations and modeling independently the quality characteristics of products at different locations is dictated for a number of reasons. First of all, for achieving adequate returns flow an extensive collection network is necessary. As most remanufacturing firms acknowledge, each of their supply sources have stable distributions of returns quality (see for example Jayaraman, 2006). However, depending on the extent of the collection network, supply sources may differ in used products quality, because of differences in end-users characteristics as for example income, social status, motivation for returning used products, differences in

* Corresponding author. Tel.: +30 2310 99 6422.
E-mail addresses: cziko@auth.gr (C. Zikopoulos), tagaras@auth.gr (G. Tagaras).

http://dx.doi.org/10.1016/j.ejor.2015.04.051
0377-2217/

the certain characteristics of the location of usage (e.g. temperature, humidity, fuel quality, electricity network stability, etc.), and differences in product life-cycle duration. Moreover, different collection locations may be considered as representations of different product models or products that were initially manufactured by different original equipment manufacturers (OEMs), which are remanufactured in a single facility to satisfy demand in a unified market. Of course, there exist RSC with similar used products characteristics at all, some or none of the available collection sites (CS).

Although the issues of multiple suppliers, random yield and the value of quality information through classification/sorting are not new in the supply chain literature, they have not been examined yet in an integrated manner. Our aim and contribution is to provide an integrated treatment of all these distinctive features of RSC in a general setting and to study their impact on operational decisions and on the profitability of RSC. More specifically, we study acquisition and remanufacturing decisions in RSC consisting of multiple collection sites with uncertain quality of returned used products. This uncertainty can be resolved to a certain extent by a sorting procedure, which in turn is subject to classification errors. We also consider the optimal choice of sorting location/timing among alternative possibilities including the no sorting option.

In addition to providing a comprehensive analysis of all these issues simultaneously for the first time, the contribution of the present paper includes a detailed analysis of the impact of the operational characteristics and accuracy of the sorting procedure on the determination of the optimal supply chain configuration and acquisition quantities, in conjunction with returns quality. Currently, there is a diversity of technological solutions and approaches for establishing returns classifications procedures; complete disassembly, specialized testing, usage-data recording, monitoring with RFID-tags and visual inspection are among the alternative classification methods employed in practice for used products quality evaluation. A more detail discussion on related issues can also be found in Van Wassenhove and Zikopoulos (2011). According to Fleischmann, Galbreth, and Tagaras (2010), there is a need for studies which compare different grading options in terms of timing, location and method used. Moreover, Fleischmann et al. (2010) point out that the lack of studies with such features in the RSC literature is remarkable, given that returns grading is among the key processes that distinguish closed-loop supply chains (CLSC) from conventional supply chains. In order to contribute toward this direction, in the current paper the sorting operation is modeled in a general way that allows the investigation and comparison of various classification options with differences in accuracy and cost.

Section 2 presents a review of the related literature and further clarifies the positioning and contribution of this paper. Section 3 explains in detail the problem setting and the basic assumptions of the model. In Section 4, the mathematical formulation is developed and the optimality conditions are examined. Section 5 compares three alternative supply chain structures differing with respect to existence and location of sorting operations that can classify used products in two classes according to their remanufacturability potential. Section 6 concentrates on the special case of identical collection sites deriving properties of the optimal acquisition policy and simple expressions for the selection of the best network configuration. Section 7 studies analytically the impact of different degrees of sorting accuracy and respective costs on the need for sorting and the optimal location of the sorting operation, if needed. Section 8 contains a numerical study that provides additional insights regarding the impact of returns quality, the number of available collection sites and the supply chain structure on acquisition and remanufacturing quantities and total system profitability. Finally, Section 9 summarizes the main results and concludes the paper. Appendix A contains the formulation of the expected profit function for RSC with sorting. All proofs are included in Appendix B.

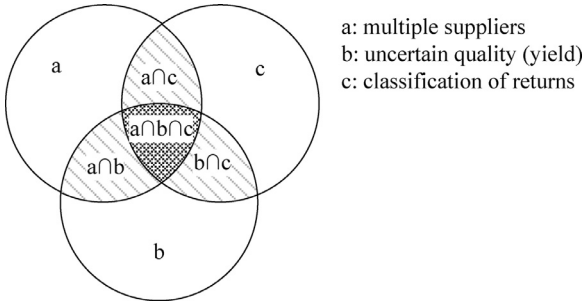

Fig. 1. Schematic representation of related research areas.

2. Literature review

The present work concerns the study of RSC where multiple suppliers (collection sites) are available. Moreover, it shares common features with a number of existing contributions which examine acquisition decisions for returned units of uncertain quality. Another related stream of literature is the one that studies the value of information on returns condition and the advisability of establishing sorting procedures in RSC. The complete review of these three literature areas is beyond the scope of this paper. In the current paper, only contributions that fall into more than one of the aforementioned categories are reviewed. Fig. 1 depicts the areas of interest as three overlapping circles. The literature review is presented separately for the three overlapping pairs that appear as shaded areas in Fig. 1, as well as for the intersection of all three areas. For more detailed analysis of the RSC literature one can refer to some of the existing literature reviews, such as Ilgin and Gupta (2010), Akcali and Cetinkaya (2011), and Govindan, Soleimani, and Kannan (2015). A review that concentrates on acquisition and sorting decisions can be found in Fleischmann et al. (2010), while Souza (2013) provides a review on strategic and tactical issues related to the management of supply chains with reverse flows of used products.

2.1. Multiple suppliers and uncertain quality

The problem of acquisition quantity determination when suppliers are unreliable has been widely addressed in RSC literature, but the combination of multiple collection sites and uncertain yield has not been examined thoroughly yet. Until now, researchers have studied either RSC with only two suppliers or RSC with a single supplier but multiple quality levels of returns. Two-supplier problems are examined in Souza and Ketzenberg (2002) and Robotis, Bhattacharya, and Van Wassenhove (2005). A problem with multiple discrete quality levels of returns is studied in Teunter and Flapper (2011) for both deterministic and stochastic demand. Galbreth and Blackburn (2010b) develop a model where returns quality is treated as a continuous variable.

2.2. Multiple suppliers and classification of returns

Although the returns stream consists of units characterized by different quality levels, a common assumption in RSC literature is that the proportion of items that fall into each quality class is deterministic. Even under this assumption, there is still the need for classification of the returns. Supply chains with large number of collection sites and deterministic quality of returns are common in studies that investigate the design of reverse logistics networks. Since, both the approach and the objective of these papers differ widely from those of the current paper, we omit a detailed review of the related literature. One of the early contributions on multiple collection location