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Impact of RFID information-sharing strategies on a decentralized supply chain with reverse logistics operations

Juan Jose Nativi *, Seokcheon Lee

School of Industrial Engineering, Purdue University, 315 N. Grant Street, West Lafayette, IN 47907-2023, USA

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A B S T R A C T

The integration of environmental practices in a supply chain has been study for the past few decades. However, most of the work relies on centralized decisions made by one player. Few papers address the complex dynamics of environmental decentralized supply chains and how these dynamics can affect environmental and economic outcomes. To study this problem, we consider a supply chain with a manufacturer and two different suppliers: a recycled-material and a raw-material supplier. The players make individual inventory decisions to satisfy demand and reduce cost. Further, this supply chain encompasses stochastic elements such as in demands, returns, and collection leadtimes. These decentralized decisions and random factors can cause underperforming results; therefore, new inventory models and technologies are needed to help companies increase coordination within these systems. We model the implementation of Radio Frequency Identification (RFID) in the supply chain to determine if real-time inventory monitoring and information sharing can help the system attain higher environmental benefits (more returns) and higher economic benefits (less cost). We study two scenarios through a simulation-based analysis: No RFID and RFID. Numerical studies show that environmental benefits are significantly increased with the attainment of more returns. However, although economic benefits are realized, they are less significant than the environmental benefits. Further regression and sensitivity analyses on the cost performance measures reveal that economic benefits depend on several drivers inside the system. We present managerial insights that illustrate what configurations within this complex system can lead to the achieving of environmental as well as economic benefits.

1. Introduction

Environmental responsibility plays a significant role in the agendas of every corporation (Cai et al., 2008). In this scenario, different drivers like government regulations have forced companies to take environmental initiatives in their supply chain operations (Zhu and Sarkis, 2004; Lee, 2008). Environmental practices can be applied through environmental design, environmental operations, and proper handling of waste and hazardous materials. In this paper, we address the environmental operations of reverse logistics, especially the collection of recycled materials used to replace traditional raw materials. Many industries apply reverse logistics to include recycled materials in their operations. For example, paper industry uses recycled materials transformed from used cartons, cardboard, newspapers, magazines, etc., for new paper production. Automotive industry uses different types of recycled materials in manufacturing tires and door covers to reduce procurement costs, and telecommunication industry uses recycled plastic materials to create new cell phone covers.

Green supply chain initiatives can provide environmental benefits. However, practices and research have shown that reverse logistic is a complex process that complicates managerial decisions in an attempt to achieve greater economic benefits (Zhu and Sarkis, 2004; Srivastava, 2007). One of the complexities that arise is the coordination with the forward supply chain in the inventory management. Reverse logistics operations handle the collection of returns; however, the amount of returns is highly uncertain and this uncertainty greatly affects the collection and inventory decisions (Dekker et al., 2004). Furthermore, the supply chain involves heterogeneous entities from both forward and reverse logistics, adding complexity into the system. As a result, though green supply chains achieve some enhancements in environmental and operational performances, they have not realized significant economic benefits, as noted by Zhu et al. (2007). For these reasons, companies need economic justifications to be fully motivated to voluntarily create environmental operations.

* Corresponding author at: 315 N. Grant Street, West Lafayette, IN 47907-2023, USA. Tel.: +1 765 494 5400; fax: +1 765 494 1299.
E-mail addresses: jnativin@purdue.edu (J.J. Nativi), lee46@purdue.edu (S. Lee).

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Our research question is then: how decentralized supply chains, through their inventory decisions, can voluntarily apply green supply chain practices such as reverse logistics in order to increases environmental as well as economic benefits?

There have been several studies and research that identify technology as a way to help managers coordinate complex decentralized systems (Surana et al., 2005; Wycisk et al., 2008). In practice, there are different kinds of information technologies such as bar codes, Global Positioning System (GPS), sensors, and Radio Frequency Identification (RFID). For our study, we are modeling the system with RFID technology. Items such as products and pallets can have attached a RFID tag. This tag will have a chip that has an Electronic Product Code (EPC). The EPC can store relevant data about the item tagged. Further, RFID Readers are installed in the warehouses in which through electromagnetic waves, it can detect the tags and read its respective data. One of the motivations for analyzing RFID technology is the capability of providing real-time monitoring of material flows in a supply chain. Also, RFID technology enables the entities in the supply chain to share EPC information through the use of the EPC Global Network (Bottani and Rizzi, 2008)[1] . Another motivation for utilizing this technology is that RFID literature still needs quantitative analyses that can guide managers to understand its implications (Lee and Özer, 2007).

The objective of this research is to investigate how RFID information-sharing can help supply chains that use reverse logistics increase environmental and economic benefits through more coordinated inventory management. We study a decentralized supply chain with a manufacturer, a recycled-material supplier, and a raw-material supplier. Our study, through a simulation-based analysis, shows that the RFID technology provides two main competitive advantages to the supply chain: (1) real-time inventory monitoring, and (2) enhanced information sharing among decision-makers. The former competitive advantage allows continuous inventory control as opposed to periodic inventory control. The latter competitive advantage facilitates coordination inside the supply chain. From an environmental perspective, our numerical experiments reveal that the returns see significant increase (i.e., 87% more returns) in the RFID versus the No RFID scenario. However, in terms of economic benefits, cost is reduced in the RFID scenario, but the percentage of change was not as high as the environmental benefit (i.e., 19% less cost). To better understand these outcomes, regression and sensitivity analyses were performed in the economic performance measures. These analyses illustrate statistically significant factors that define what supply chain configurations can attain higher economic benefits.

The novelty of our work relies on three main contributions. First, there are rare papers in literature that address the inventory control on reverse logistics and its respective supply chain with multiple decentralized players. Second, few papers convey the modeling complexity of the decentralized system including stochastic behaviors such as in demands, returns and collection leadtimes as we modeled. And finally, this research is among the very first endeavors that quantitatively analyzes through a simulation-based study the usefulness of RFID information-sharing strategies in a green supply chain context.

The rest of this paper is organized as follows: Section 2 presents a literature review relevant to our research. Section 3 depicts system descriptions, notations and model assumptions. Section 4 presents system performance measures. Section 5 defines the inventory policies resulting from No RFID and RFID scenarios. The numerical results and managerial insights are analyzed in Section 6 and finally Section 7 discusses conclusions and future research.

[1] The Electronic Product Code (EPC) global network is managed by the EPC global organization. This computer network helps companies to exchange RFID information between trading partners.

2. Literature

Literature review about inventory control models on reverse logistics is first presented. We review optimal and heuristic models in literature. Then, we introduce the literature of quantitative models on RFID information technology.

2.1. Inventory control models on reverse logistics

Academics and practitioners have studied inventory models for reverse logistic for the past few decades. The inventory models for reverse logistics can be analyzed under three main classifications: (1) deterministic or stochastic models, (2) single or multiple period analyses, and (3) single or multiple stocks options (Dekker et al., 2004; Dyckhoff et al., 2004). Our research focuses on stochastic models in a multiple period analysis with two inventories: serviceable and returns inventory. Below are the relevant papers that address these models.

Simpson (1978) studied a manufacturer with serviceable inventory, repairable inventory, and disposal options. The author found that optimal decisions are based on three parameters with the use of backward dynamic programming. The limitations of the study are zero leadtimes and zero setup costs. Inderfurth (1997) investigated a similar case with positive-similar setup cost and deterministic leadtimes. The author showed that an optimal policy can be achieved under positive but identical leadtimes and proper definition of inventory positions.

These two papers described above address optimal approaches. However, these models have strong assumptions such as leadtimes and setup cost constraints. For these reasons, many authors began to use heuristic solutions to model these systems (Dyckhoff et al., 2004). van der Laan et al. (1999a) introduced the PUSH and PULL heuristic models with remanufacturing operations. In the PUSH models, returns are used for serviceable inventory only when there are enough recycle items recovered to complete the entire batch. In the PULL model, if the inventory position is below than or equal to the reorder point to-remanufacture, and if sufficient recycle items are available, a remanufacturing order is produced. However, if there are not enough returns and inventory position is below than or equal to the reorder point to-manufacture, a manufacturing batch is ordered. The authors found that leadtimes present challenges to attain higher economic performances. Their results illustrated that better performance is attained when leadtimes are relatively equal. van der Laan et al. (1999b) extended previous research and analyzed stochastic leadtimes into the model. Results showed that manufacturing leadtimes have more significant impact than remanufacturing leadtimes. Also, the authors found that in some cases larger remanufacturing leadtimes and larger variability in the manufacturing leadtimes can decrease cost, which is counter-intuitive. To tackle this phenomenon, Inderfurth and van der Laan (2001) further studied leadtime effects and provided a policy improvement taking leadtimes as a decision variable. The main limitations of this article are that obtaining the optimal solution is quite time-consuming and the problem does not consider differences in leadtimes. Also, leadtimes are considered as one of the decision variables. In real cases, leadtimes are mostly fixed based on the supply chain structure.

Kiesmüller (2003) provided a novel solution from previous inventory control models on reverse logistics. The author split the