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Designing a multi-echelon reverse logistics operation and network: A case study of office paper in Beijing

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ABSTRACT

To develop a circular and low-carbon economy, it is important to recycle and reuse office supplies, particularly office paper. We have analyzed the characteristics of office paper reverse logistics and propose an appropriate operation mode: a strategic alliance and third-party reverse logistics union led by a government or non-profit organizations and including office paper producers. We propose a nonlinear integer programming model for determining the locations and numbers of recycling stations and plants, such that the total cost is minimized. A case study of selected sites along the Xueyuan Road in Beijing is used to illustrate the proposed model. Additionally, our sensitivity analyses investigated how the amount of waste office paper, the throughput capacity of recycling stations, and the unit transportation cost affected the optimized results. Our findings provide useful insights for various stakeholders and suggest avenues for further research.

1. Introduction

Office paper has become a necessity of study and work since the appearance of computers, printers and other automated office equipment. At present, China's paper industry is challenged by a lack of raw materials and environmental pollution. According to the "2012 Annual Report of China's Paper Industry" (China Paper and Association, 2012), China's production of paper and paperboards increased annually by 10.13% from 2003 to 2012, and its consumption increased by 8.54%. In 2012, China consumed 16.84 million t of printing and writing paper (i.e., office paper), which represents 16.76% of the total consumption. However, a large proportion of waste office paper is discarded instead of being recycled and reused (China Paper and Association, 2012). This is a massive waste.

Reverse logistics has become popular in many sectors. It helps to develop a circular and low-carbon economy, and to build a resource-saving and environmentally friendly society. Reverse logistics offers opportunities for companies to save costs, increase efficiency, and gain new customers and suppliers. It can potentially be used to gain a competitive advantage and to generate future profits (Kumar et al., 2012). The reverse logistics of office paper may help to decrease the level of greenhouse gases (Counsell and Allwood, 2007; Dias and Arroja, 2012). Green procurement (of office materials, recycled toner cartridges, etc.) has also been highlighted as a powerful tool for extending good environmental practices throughout society to achieve more sustainable development (Bala et al., 2008). Vanek (2000) presented a product manufacturing and distribution system model, and predicted the environmental impact caused by either changes in taxation or input costs. Berglund et al. (2002) applied two regression models to conclude that waste paper recovery and use are largely market-determined, and depend on long-standing economic factors such as population intensity and competitiveness. Arminena et al. (2013) explored how economic, demographic, and environmental factors affected the recovery and use of recycled paper. They confirmed the roles of economic determinants, but also indicated that concern for the environment has an impact on the recovery of recycled paper, particularly in high-income countries.

Over the past decade, waste paper pulp has been the fastest growing type of pulp in China (China Technical Association of Paper Industry, 2012). There is a trend toward recycling and reusing waste office paper. An attractive alternative is to recycle office paper within the office, without destroying its mechanical structure (Counsell and Allwood, 2006). However, this technique has not been fully developed. A limited amount of companies are capable of producing and processing waste office paper, so it must be recycled through different channels. We must, therefore, design an operation mode and network for the reverse logistics of office paper.

The reminder of this paper is organized as follows. Section 2 contains a review of related work. The features and operation mode for office paper reverse logistics are presented in Section 3. In

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Section 4, we propose a nonlinear mixed integer programming model for deriving the optimal network structure of office paper reverse logistics. Section 5 contains a case study that illustrates the proposed method, and a sensitivity analysis of some important parameters. Finally, our conclusions and future research directions are presented in Section 6.

2. Literature review

2.1. Common operations of reverse logistics

An increasing interest in environmental issues has encouraged research into reverse logistics. According to Rogers and Tibben-Lembke (2001), reverse logistics is the process of planning, implementing, and controlling raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin, to recall value or for appropriate disposal. An important topic of reverse logistics is the design of the operation and network structure.

Reverse logistics operations can be divide it into three typical categories according to the participants: the self-owned reverse logistics mode, the strategic alliance reverse logistics mode, and the third-party reverse logistics mode. The reverse logistics network is designed on the basis of these modes.

(1) Designing a self-owned reverse logistics operation and network

Jayaraman et al. (2003) developed a mathematical programming model for reverse logistics distribution networks, and presented a heuristic solution methodology. Amini et al. (2005) analyzed a case study of an international medical diagnostics manufacturer to illustrate how to design a reverse logistics operation for a repair service supply chain that minimizes the total cost. Kara et al. (2007) presented a model of a reverse logistics network for collecting end-of-life appliances in the Sydney metropolitan area. To establish a closed-loop supply chain for collecting end-of-life vehicles in Mexico, Cruz-Rivera and Ertel (2009) presented a reverse logistics network and modeled an uncapacitated facility location problem. A multi-stage and multi-product model was developed by Lee et al. (2009) for disassembly and processing centers in the remanufacturing system. Achillas et al. (2012) proposed a multicriteria optimization model for multi-type carriers of waste electrical and electronic equipment based on multiple objective linear programming. Das and Chowdhury (2012) considered the overall planning process in terms of maximizing profit when collecting returned products and recovering modules. They proposed a mixed integer programming model. A model was proposed by Alfonso-Lizarazo et al. (2013) to represent the dynamic interaction between forward and backward product flows in a palm oil closed-loop supply chain. An integrated production inventory model for reworkable items with an exponential demand rate was developed by Raj et al. (2014), etc.

(2) Designing a strategic alliance reverse logistics operation and network

Sheu et al. (2005) presented a linear multi-objective programming model of forward and reverse logistics in a given green-supply chain. To determine the number and location of centralized return centers, Min et al. (2006) developed a nonlinear mixed integer programming model. A mathematical model for the design of a reverse logistics network was proposed by Mutha and Pokharel (2009). They assumed that the returned products must be consolidated before they are sent to reprocessing centers, etc.

(3) Designing a third-party reverse logistics operation and network

A mixed integer nonlinear programming model for the design of a dynamic integrated distribution network of third party logistics providers was presented in (Ko and Evans, 2007). Mahmoudzadeh et al. (2013) proposed a mixed integer linear program for determining the optimal location, allocations, and material flows of scrap yards in Iran. Suyabatmaz et al. (2014) presented a hybrid simulation-analytical model for designing the reverse logistics network of a third-party logistics provider, etc.

Researchers have also developed a general conceptual framework for reverse logistics. Fleischmann et al. (2000) identified characteristics of product recovery networks by categorizing them into bulk recycling, assembly product remanufacturing, and reusable items. They then classified the network characteristics within each type. Barker and Zabinsky (2008) defined eight different configurations for reverse logistics and closed loop supply chains, based on whether the collection was industry wide or company-specific, whether sorting/testing was distributed or centralized, and whether the subsequent processing facility was original or secondary. Zhou and Wang (2008) proposed a generic model for reverse logistics that simultaneously considered repairing and remanufacturing options. Srivastava (2008) developed an integrated holistic conceptual framework that combined descriptive modeling with optimization techniques. El Korchi and Millet (2011) introduced a framework that generated and assessed different reverse logistics channel structures. Lambert et al. (2011) proposed an improved conceptual framework for reverse logistics decisions. Alumur et al. (2012) presented a mixed-integer linear programming formulation for multi-period reverse logistics. A multi-agent architecture for recycling and reverse logistics issues was proposed in Mishra et al. (2012). Bai and Sarkis (2013) introduced operational and strategic flexibilities to manage uncertainties in reverse logistics systems. The effect of remanufacturing in an integrated production inventory model consisting of forward and reverse supply chain over infinite planning horizon was investigated by Singh et al. (2013). Zhou et al. (2013) proposed a construction green supply chain management model for maximizing the aggregate profits of normalized construction logistics, reverse logistics, and the environmental performance. Niknejad and Petrovic (2014) discussed a problem of inventory control and production planning optimization of a generic type of an integrated reverse logistics network. Combining environmental considerations and uncertainties, a fuzzy programming model for bi-objective supply chain network design was proposed by Saffar and Razmi (2015), etc. This general type can be grouped into one or two of the above mentioned operations and networks.

2.2. Existing papers on reverse logistics design

Bloemhof-Ruwaard et al. (1996) used a linear programming model to analyze European pulp and paper production with different recycling strategies. Kleineidam et al. (2000) presented a production chain model based on control theory, which they demonstrated using a paper recycling example. Fleischmann et al. (2001) presented a generic facility location model and analyzed the design of a logistics network for a European paper producer that considered raw material transportation costs. Pati et al. (2008) formulated a mixed integer goal programming model to assist in the proper management of a paper recycling logistics system. Kara and Onut (2010) presented a two-stage stochastic revenue-maximization model to determine a long-term strategy under uncertainty, for a large-scale real-world paper recycling company. A life cycle assessment was conducted by Hong and Li (2012) to estimate the environmental impact of producing printing and writing paper from wastepaper in China. Liang et al. (2012) investigated the environmental impacts of four categories of waste recycling in China's paper industry: crop straws, bagasse, textile wastes, and scrap paper. They also constructed a physical input–output